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SPECIAL FEATURES

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TRANSACTIONS

of the

American Society for Steel Treating

Vol. IV **Cleveland, October, 1923** **No. 4**

INITIATIVE

ELBERT HUBBARD rightly said that "the world bestows its big prizes, both in money and honors, for but one thing. And that is *Initiative.*"

What is Initiative? He answers that "it is doing the right thing without being told. But next to doing the thing without being told is to do it when you are told once. That is to say, carry the message to Garcia. Those who can carry a message get high honors, but their pay is not always in proportion. Next, there are those who never do a thing until they are told twice. Such get no honors and small pay. Next, there are those who do the right thing only when necessity kicks them from behind, and these get indifference instead of honors, and a pittance for pay. This kind spends most of its time polishing a bench with a hard luck story.

"Then, still lower down in the scale than this, we have the fellow who will not do the right thing even when someone goes along to show him how and stays to see that he does it. He is always out of a job, and receives the contempt he deserves, unless he happens to have a rich Pa, in which case Destiny patiently awaits around the corner with a stuffed club."

How many do you know who fits each class? The successful man can only come from, and belong to, the first. He must have initiative to climb high on the ladder of success.

REPORT OF FIFTH ANNUAL CONVENTION

THE October issue of TRANSACTIONS goes to press on the eve of the fifth annual convention of the Society. A complete report of convention activities will appear in the November issue of TRANSACTIONS.

HENRY MARION HOWE MEMORIAL SERVICE

AT THE Episcopal Cathedral of St. John, the Divine, One hundred and tenth street and Amsterdam avenue, New York City at 5:00 p. m. on Thursday, Oct. 25, 1923, will be held a memorial service for the late Dr. Henry Marion Howe, president of the American Institute of Mining Engineering in 1893, in whose memory the institute has recently established the Henry Marion Howe Lecture.

The memorial service will be largely musical, by the Cathedral organist and choir, with short addresses. Dr. Nicholas Murray Butler, president of Columbia university, has been asked to be one of the speakers. Doctor Howe was a vestryman in an Episcopal church in this diocese. He combined the qualities of the great scientist with those of a devout christian. Bishop Manning and Dean Robbins idealized the service as an expression of the harmony which can and does exist fundamentally between science and religion, when understood profoundly.

After conference between Bishop Manning and Judge Gary, as president of the American Iron and Steel institute, the date of the service was selected so as to coincide with the autumn meeting of the American Iron and Steel institute. Owing to the absence of Mrs. Howe, it was deemed best not to hold the service at the time of the annual meeting of the American Institute of Mining Engineering last February. The directors of the American Institute of Mining Engineering have, however, appointed a committee to co-operate with Dean Robbins in arranging the details of the service, and it is hoped that many members of the institute in the East will attend it. The Cathedral is more than large enough to seat all who can and will come. Everyone is invited who is interested or attracted by the beauty of the service, or desires to join in this token of respect to our late distinguished past-president.

GEORGE KIMBALL BURGESS
National President of the American Society for Steel Treating

Officers of The American Society for Steel Treating

1923-24

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Milwaukee, Wis.

NEW OFFICERS

THE tellers of election have counted the ballots cast by the membership of the American Society for Steel Treating and the following new officers have been elected: President, Dr. George K. Burgess, director, Bureau of Standards, Washington, D. C.; second vice president, Robert M. Bird, engineer of tests, Bethlehem Steel Company, Bethlehem, Pa.; treasurer, Zay Jeffries, research bureau, Aluminum Company of America, Cleveland; director, J. Fletcher Harper, research engineer, Allis-Chalmers Mfg. Company, Milwaukee, Wis.

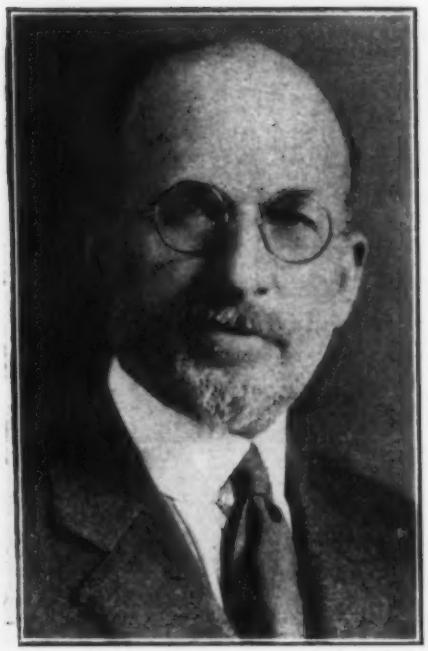
The board of directors of the society will be composed of the newly elected officers and the following: First vice president, W. S. Bidle, president, W. S. Bidle Company; secretary, W. H. Eisenman, 4600 Prospect avenue, Cleveland;

W. S. BIDLE
First Vice President of the Society

ROBERT M. BIRD
Second Vice President of the Society

W. H. EISENMAN
National Secretary of the Society

ZAY JEFFRIES
National Treasurer of the Society



T. D. LYNCH
Past President
National Director of the Society

F. P. GILLIGAN
Past President
National Director of the Society

S. M. HAVENS
National Director of the Society

J. FLETCHER HARPER
National Director of the Society

director, T. D. Lynch, past-president, manager, M. & P. engineering department, Westinghouse Electric & Mfg. Company, East Pittsburgh; director, F. P. Gilligan, past-president, secretary-treasurer, Henry Souther Engineering Company, Hartford, Conn.

The new officers will begin their duties at the close of the annual convention of the Society at Pittsburgh, October 8 to 12, 1923.

The report of the tellers of election is as follows:

August 15, 1923.

To the Secretary,
American Society for Steel Treating,
4600 Prospect Avenue,
Cleveland, Ohio.

The Committee of Tellers begs to submit the results of the balloting by the membership for National Officers of the American Society for Steel Treating.

These ballots were received by the Committee, opened, examined, and counted in the National Headquarters of the Society at 4600 Prospect Avenue, Cleveland, Ohio.

The signature of each voting member written on the outside of the envelope had previously been verified by Secretary W. H. Eisenman, and found to be correct.

The tabulation of the count is as follows:

	For	Scattering	Defective	Total
For President				
One Year				
G. K. Burgess	919	4	36	959
For Second Vice President				
Two Years				
Robt. M. Bird	922	1	36	959
For Treasurer				
Two Years				
Zay Jeffries	920	3	36	959
For Director				
Two Years				
J. F. Harper	896	27	36	959

Respectfully submitted,
Committee of Tellers.
C. W. SIMPSON,
C. M. CAMPBELL,
C. G. SHONTZ, Chairman.

THE THEORY IN QUENCHING STEELS

By Kotaro Honda

Abstract

The author of this paper, a well known authority on the metallurgy of iron and steel, has reviewed in considerable detail the theory of the mechanism and principles involved in the quenching of steels.

Quenching cracks are closely studied and the author points out that the generally accepted cause of the cracking of high carbon steels by quenching in water, is not as evident as has been supposed. The nonuniform distribution of temperature and the difference in martensite expansion of adjacent parts during quenching, are not alone the causes of quenching cracks, because, as the result of the author's experiments it was found that cracking occurs only when the quenching temperature exceeds the A_1 point. The cracks, therefore, must have some connection with the A_1 transformation. The author develops the theory in this connection as based upon experimental data. Hardness tests of specimens quenched from various temperatures are included in this paper. In conclusion the author suggests a remedy for eliminating quenching cracks.

Principle of Quenching

THE quenching of a steel in its heat treatment originally means the suppression of a transformation by a rapid cooling. This rapid cooling is usually obtained by plunging a heated steel in cold water or oil. If a metal possessing a transformation at a high temperature be heated above this temperature and then cooled very rapidly, the transformation is partially or wholly arrested. The metal requires a certain time to perform a transformation, and if this time is insufficient, the transformation cannot progress at all, or goes on a little, before the metal cools to room temperature; but any transformation taking place very easily at high temperature scarcely goes on at room temperature, owing to the great viscosity of the metal at low temperature. Thus, by

A paper presented at the annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, Kôtarô Honda, is professor of metallurgy, Tôhoku Imperial University, Sendai, Japan. Written discussion of this paper is invited.

water quenching a metal possessing a transformation, from a temperature above the transformation point, the state or the phase at the high temperature can be preserved at room temperature. Hence we can easily study its structure microscopically. This is the principle of quenching and is widely used in the science of metallurgy; its absolute validity is generally admitted.

Quenching of Steels

Take for the sake of simplicity, the case of quenching of a 0.90 per cent carbon steel. Above the A_1 point, the steel has an austenitic structure consisting of a solid solution of carbon in γ-iron, and below it a pearlitic structure consisting of a mechanical mixture of ferrite and cementite forming the well-known lamellar distribution. Hence by quenching the steel above the A_1 point, it is to be expected to have an austenitic structure, or if the quenching is not sufficiently effective, a pearlitic structure. Contrary to our expectation, we obtain a structure quite different from either of them. This structure consists of very fine needle-shaped crystals known as martensite; being a very hard homogeneous phase consisting of a solid solution of carbon in α-iron. By X-ray analysis, Dr. Westgren[1] has shown that in the austenitic region, i. e., above the A_3 point, iron has a face-centered cubic lattice, but below it a cubic centered, thus the A_3 transformation in iron being the change of atomic configuration from a face-centered cube to a cube-centered, or vice versa, and that the atomic configuration in martensite is the body-centered cube as in α-iron, but differs from the latter in taking carbon atoms in the interspace of the cubic lattice. From the diffusion of the spectrum lines, he also concludes that individual crystals constituting the martensitic structure are very fine, each containing only several hundreds of atoms. There is thus no doubt that martensite is a solid solution different in phase from austenite, differing of course from pearlite.

If by quenching a steel, neither austenite nor pearlite, but martensite, is obtained, the principle of quenching is violated, and hence numerous results of investigations hitherto made by many metallurgists in observing the microstructure of quenched metals and alloys may not be true. The formation of martensite by

1. Iron and Steel Institute, 1921, No. 1; 1922, No. 1.

quenching is thus a very important and serious problem in metallurgy; hence it is much to be desired that if possible, the above problem will be so explained as to conform with the principle of quenching.

The Theory of Quenching

From the structural point of view, the A_1 transformation consists of

$$\text{austenite} \rightleftarrows \text{pearlite},$$

but according to the present writer,[2] this shows only the result of the transformation, and the change itself consists in reality of the stepped change, that is,

$$\text{austenite} \rightleftarrows \text{martensite} \rightleftarrows \text{pearlite}$$

or

$$\text{solid solution } \gamma \rightleftarrows \text{solid solution } \beta \rightleftarrows \text{Fe} + \text{Fe}_3\text{C}.$$

During a slow cooling, at the A_1 point, austenite first changes into martensite, and the latter being at the high temperature, changes immediately into pearlite, the result being the same as

$$\text{austenite} \rightarrow \text{pearlite}.$$

During a very rapid cooling, such as quenching, the change from austenite to martensite is so far retarded that it begins to take place at below 300 degree Cent. (572 degrees Fahr.), and when this change is completed, the specimen is nearly at room temperature, and hence the second change from martensite to pearlite cannot progress, owing to the great viscosity of the specimen at room temperature. Thus by quenching the steel in water, martensite is obtained. This explanation does not at all contradict the principle of quenching.

Since during cooling, the change from austenite to pearlite always occurs through an intermediate phase martensite, it is natural to assume that during heating, the A_1 transformation, that is, the change from pearlite to austenite takes place through martensite, unless some negative facts are found.

According to the above theory of quenching, the perfect quenching is obtained when the first change in the stepped transformation, austenite→martensite, completely takes place, and the second change, martensite→pearlite, is completely suppressed. In the case of a less rapid cooling, the first change occurs at a

2. *Science Reports* 8 (1919), 181; 11 (1922), 489. K. Honda and T. Matsushita. *Science Reports* 8 (1919); K. Honda and S. Idei; *Science Reports* 9 (1920), 491.

little higher temperature than in the above case, and therefore the second change partially progresses, resulting in a martensitic structure mixed with pearlite (troostite in actual case). Since the hardnesses H of austenite, martensite and pearlite satisfy the following relation,

$$H_{\text{austenite}} < H_{\text{martensite}} > H_{\text{pearlite}}$$

the hardness of the martensite mixed with pearlite is less than that of pure martensite. This is the case of an imperfect quenching.

In the case of an extremely rapid cooling, not only the second change is completely suppressed, but even the first change is partially suppressed. We then obtain a martensitic structure mixed with austenite, the hardness of which is less than that of pure martensite. This is the case of a too severe quenching. In such a case, however, a little tempering at a temperature below 100 degrees Cent. which accelerates the change of the remaining austenite into martensite, increase its hardness slightly.

Equilibrium Diagram of Iron-Carbon System and the Stepped Transformation

Fig. 1 is that portion of the constitutional diagram of the iron-carbon system, which has the connection with the A_1 transformation. The A_3 point of pure iron is lowered by the addition of carbon along the line A_3E, till it reaches the eutectoid horizontal A_1C at point E. Above the eutectoid concentration E, the A_3 line coincides with the eutectoid line EC. EB is the solubility line of cementite in γ-iron or austenite. The dotted horizontal is the A_2 line; this line is so drawn, since the A_2 transformation is not the change of phase.

From the equilibrium diagram, it is to be concluded that along line A_3E, double processes consisting of the A_3 change and the precipitation of ferrite begins to take place, and that along line EC, in which the A_3 point falls, the above double processes occur at the same temperature. Since the A_3 transformation during cooling consists of the change of configuration in iron atoms from the face-centered cube to the body-centered, carbon being still present as a solid solution, the first change of the double processes in the case of steels is nothing but the change, austenite→martensite, and the second change, that is, the precipitation of ferrite

from martensite is the change, martensite→pearlite. Thus the double processes just referred to are the same as the stepped change before mentioned, that is,

austenite→martensite→pearlite

Suppose we cool a hypereutectoid steel from the austenitic region; on reaching line EB, cementite begins to precipitate from austenite and continues to do so, as the temperature falls, till the concentration of the remaining austenite reaches that of eu-

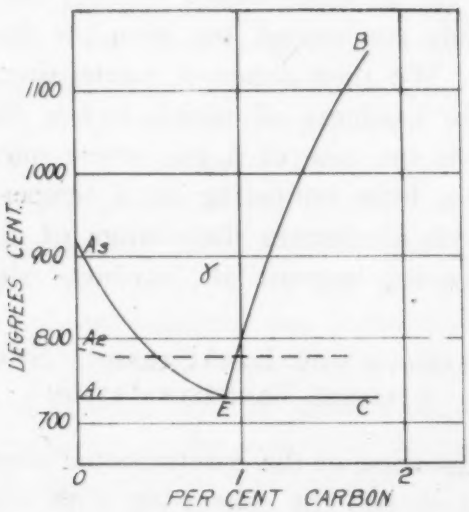


Fig. 1—Portion of Constitutional Diagram of the Iron-Carbon System

tectoid. At this point, the austenite makes the A_1 transformation, that is, the A_3 transformation immediately followed by alternate precipitations of ferrite and cementite in virtue of alternate supercoolings, giving rise to the well known lamellar structure. Thus the A_1 transformation here consists of the changes,

austenite→martensite→pearlite

Since the nature of the A_1 transformation is the same both for the hypo and hypereutectoid steels, it is to be concluded that for the whole carbon concentrations ranging from 0 to 6.7 per cent, the A_1 transformation must, in its nature, consist of the changes,

austenite→martensite→pearlite

On the other hand, if we cool the hypoeutectoid steel from the austenitic region, on reaching line A_3E, a small quantity of

austenite first makes the A_3 transformation, and then from this transformed product,—martensite—, the precipitation of ferrite follows. As the steel further cools, the remaining austenite gradually makes the same changes, till the concentration of austenite reaches the eutectoid at point E, where the remaining austenite makes the stepped change above referred to at the constant temperature.

We have seen in the above that the change, austenite→martensite, is in reality the A_3 transformation, and hence the heat of the change must be equal to that of the A_3 transformation in pure iron, a small allowance being made for the presence of the dissolved carbon atoms. Meuthen[3] found by his careful experiment, the heat of the A_3 transformation in pure iron to be 5.6 calories per gram. On the other hand, N. Yamada[4], directly measured the heat of transformation, austenite→martensite, for a eutectoid steel and found it to be 5.66 calories per gram of iron. Thus the coincidence between these two is very satisfactory.

In a former paper,[5] Dr. T. Matsushita has shown that in carbon steels, there exist two kinds of martensite α and β, the A_1 transformation during cooling taking place in the order.

Austenite→β-martensite→α-martensite→pearlite,

and that during a slow heating of a quenched steel, α and β martensites are tempered at about 180 and 280 degrees Cent. respectively. Since these martensites have both a body-centered cubic lattice with regard to iron atoms, the difference between them consists very probably in the mode of distribution of carbon atoms within the space-lattice of iron atoms. Thus strictly speaking, the A_1 transformation consists of three steps taking place one after the other.

The following analogy will also assist the understanding of the stepped transformation. Suppose a sphere to rest on a stepped stand of the form as shown in Fig. 2, and the stand to undergo a continuous vibration, which corresponds to the thermal condition of steel. Let us further suppose that the positions A and B in the stand are much more stable than that of C. The positions of the sphere at A, B and C are assumed to correspond to austenite, pearlite and martensite, respectively. When the equilibrium

3. Ferrum, 10, (1913), 1.
4. *Science Reports* 10, (1921), 453.
5. *Science Reports* 7, (1918), 43.

of the sphere at A is disturbed, the sphere falls at first to position C; if the vibration of the stand is considerable, it falls again to position B. These stepped falls are similar to the change of austenite to pearlite through martensite at high temperatures. If, however, during the fall of the sphere from positions A to C,

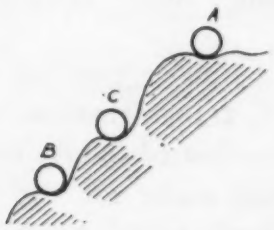


Fig. 2—Illustrating Stepped Transformation in Steel

the vibration of the stand decreases to a less intensity, the sphere will remain in equilibrium at position C. This case corresponds to the quenching of a steel.

In the same way, we may also conceive between two positions A and B two or more intermediate positions C_1, C_2, ... , corresponding to *a* and *β* martensites, and so forth.

Troostitic and Sorbitic Structures

In the above theory of quenching, the perfect hardening is obtained, when the first change in the stepped transformation

austenite→martensite→pearlite

takes place completely and the second change is arrested, while an imperfect hardening corresponds to the case, when the first change goes on completely, but the second only partially. Fig. 3 is a diagram illustrating the mechanism of quenching and similar to that already given by Professor Sauveur in his well known textbook. *a* is the case of a slow cooling, where the change from austenite to pearlite takes place at a constant temperature of 700 degrees Cent. (1292 degrees Fahr). *b* is the case of the perfect hardening; here owing to a very rapid cooling, the change from austenite to martensite begins to take place at about 300 degrees Cent. and is completed near room temperature, the second change from martensite to pearlite being suppressed. *c* is the case of an imperfect quenching; owing to the slower rate of cooling than in

the last case, the first change begins to occur at about 450 degrees Cent. (842 degrees Fahr.) and when it is completed the specimen is still at a higher temperature, and hence the second change occurs, before it is cooled to room temperature. This change consists of the precipitation of cementite as fine colloidal particles from a martensitic solid solution; this structure, when polished, is

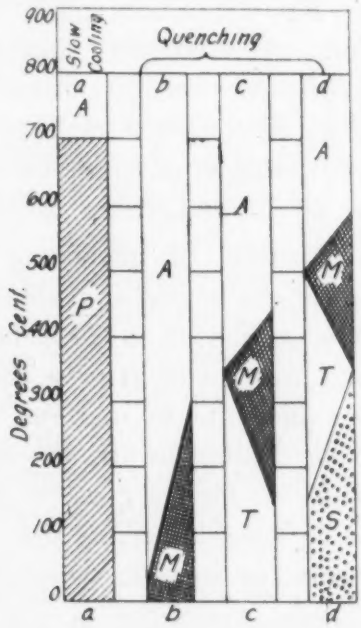


Fig. 3—Diagram Illustrating the Mechanism of Quenching

A—Austenite; M—Martensite;
T—Troostite; S—Sorbite

easily etched in acid and by virtue of a minutely roughened surface due to the presence of cementite particles appears black, even to the naked eye. It is usually called, troostite.

In *d*, the cooling is still slower, and therefore, the first change occurs at a higher temperature than in the last case. Hence the formation of troostite takes place at higher temperature, so that if the further cooling to room temperature is conducted very slowly, troostitic particles coagulate to some extent by virture of the surface tension. This structure called sorbite, is less easily etched by acid than the troostitic structure, but more readily than the pearlitic structure.

By properly adjusting the rate of cooling, either one of three

structures, martensite, troostite or sorbite, can be obtained. Troostite and sorbite are the mechanical mixtures of ferrite and cementite, and therefore the same as pearlite in their nature.

In practice, it is usual to obtain troostite and sorbite by tempering quenched steels. The martensite, when left itself at room temperature, hardly changes into pearlite owing to the high viscosity of the material at this temperature, but when it is raised to 300 to 400 degrees Cent. the martensite slowly changes into troostite by the deposition of fine cementite particles. By raising the reheating temperature to 500 to 600 degrees Cent. for a certain interval of time, the coagulation of troostitic particles goes on to such a degree that the structure becomes sorbitic.

Besides the usual method of quenching and tempering, we frequently use a stepped quenching for obtaining a troostitic or sorbitic structure. The specimen is first heated above the A_1 point, then plunged into water and after a short interval of time, when the change from austenite to martensite is just completed, taken out. When during cooling in air, the change from martensite to troostite or further to sorbite goes on completely, the specimen is again quenched in water to arrest the change at this stage; we thus obtain a troostitic or sorbitic structure.

The velocity of a transformation in a pure metal generally decreases when it contains impurities or is alloyed with other metals. Thus the A_1 transformation goes on very slowly in special steels, such as nickel, chromium and manganese steels. In these steels, the structures, such as austenite and martensite, which are hardly or only obtainable by a very rapid cooling in the case of carbon steels, can be obtained by air cooling or at ordinary rates of cooling.

Quenching Cracks

It is a well-known fact that during the quenching of high carbon steels in water, cracks are often formed on their surfaces. The cause[6] is generally believed to be:

1. The nonuniform distribution of temperature in the specimen during quenching.

6. McCance, *Journal* of the Iron and Steel Institute, 1914, No. 11, pp. 235, 247.

2. The difference in martensitic expansion of adjacent parts during quenching.

A closer examination of the phenomenon shows, however, that the true cause is not so evident, as the sound due to cracking is often heard some ten seconds after quenching. The thermal stress is maintained so long as the temperature is not uniform throughout the specimen. For instance, in a short cylinder,[7] about 2 centimeters in thickness and height, the difference in temperatures between the interior and exterior parts, during the first stage of the quenching process, may amount to several hundred degrees, and consequently a great stress will result, but after about ten seconds it does not exceed 20 degrees and hence there is only a small residual stress. Again, at the moment of transformation of austenite into martensitic during cooling, considerable expansion in volume occurs. In the case of rapid cooling the transformation does not, however, take place at the same moment at the outside and the inside of the specimen. A great stress due to unequal martensitic expansion will result which may lead to cracking, although after several seconds, during which the A_1 transformation passes over the whole mass, this stress will also vanish.

If the cracks were due to the two causes above mentioned, why do they not take place during the first stage of quenching, when the specimen is undergoing a large amount of internal stress, and why do they take place after a lapse of time? It is, of course, conceivable that at a very high temperature, the material yields to an enormous thermal stress, and therefore this stress is partially released, in which case a thermal stress of considerable magnitude may result at room temperature, and may be the cause of the cracks occurring some ten seconds after quenching. During a very rapid cooling, such as quenching in water, the release of the stress, which requires a certain interval of time, is probably very small.

In order to show that the cause of quenching cracks is not pure thermal stress[8], the following experiment was made: Several cubes, 2 centimeters on each side, were made of steel containing 1.26 per cent of carbon. They were quenched in water from dif-

7. *Science Reports* 8 (1919), 36.
8. K. Honda and S. Idei, *Science Reports*, 9.

ferent high temperatures, and the quenching temperature at which cracking occurred, was observed.

The following table contains the result of the experiments:

Table I

Heating

Quenching Temperature Degrees Centigrade					
	680	700	750	770	800	830
Remarks—	No Crack	No Crack	No Crack	No Crack	Crack	Crack

Cooling

Quenching Temperature Degrees Centigrade—Specimens first heated to 900 degrees Centigrade, then cooled and quenched					
	800	770	750	730	710	690
Remarks—	Crack	Crack	Crack	Crack	Crack	No Crack

From this table, it is seen that during heating the crack does not occur unless the quenching temperature exceeds 800 degrees Cent. During cooling from 900 degrees Cent. the quenching crack is always observed down to a temperature of 700 degrees Cent. and not observed at any lower temperature. This limiting temperature is much lower than that during heating. As is well known, the Ar_1 point is always lower by about 40 to 80 degrees Cent. than the Ac_1 point; hence, from the above result of quenching experiments, it may be concluded that during heating or cooling the crack occurs when, and only when, the quenching temperature exceeds the Ac_1 or Ar_1 point, respectively. Hence the cause of quenching cracks is not pure thermal stress caused by nonuniform distribution of temperature due to rapid cooling, because if such were the case, there would be no reason for the cracks occuring beyond the A_1 point. The cracks must, therefore, have some connection with the A_1 transformation.

In a quenching, cracks usually occur in ten to fifteen seconds after quenching in water; they can be distinctly detected by the sounds accompanying cracking. The same fact also indicates that the thermal stress is not the direct cause of cracking; because the cracking occurs after a lapse of time, where a greater part of the thermal stress due to the unequal cooling of the specimen passes off. As is well known, during cooling through the Ar_1 point, the specimen undergoes a considerable expansion due to the

A_1 transformation.[9] Since during cooling the outer portion is always at a much lower temperature than the inner portion, the former, during the said transformation, exerts a great impulsive

73	64	69	73	77	79
70	71	63	72	77	77
70	42	44	48	57	79
71	45	43	47	55	79
69	66	53	55	67	78
70	70	68	70	68	73

Fig. 4

75	72	70	74	74	77
69	68	67	69	70	72
68	65	68	68	65	69
68	67	68	67	69	70
70	68	65	67	70	75
73	72	73	69	73	76

Fig. 5

tension on the latter, and this may cause a crack in the specimen. The fact that cracks generally occur after the impulsive stress due to the Ar_1 transformation is passed over, shows that the impulsive stress is not the actual cause of quenching cracks.

Hardness Measurements of Quenched Steels

The result[10] of experiments on the measurement of hardness in quenched carbon steels by means of a Shore scleroscope will be next described. The specimens were tested in the form of a cube each side being 2.7 centimeters.

1. In a soft quenching, such as in oil from a temperature not exceeding 820 degrees Cent. the hardness of different specimens is greatest in the outer portion, and decreases from its periphery towards the center (Fig. 4).

2. In a medium quenching, such as that of a 0.91 per cent carbon steel at 780 degrees Cent. in water, or that of a 1.47 per cent carbon steel at 900 degrees Cent. in oil, hardness is nearly constant everywhere (Fig. 5).

3. In a hard quenching, such as that of a 0.68 per cent

9. K. Honda, *Science Reports*, 6, (1917), 203.
10. K. Honda and S. Idei, *Service Reports*, 9.

carbon steel from 800 degrees Cent. or a higher temperature in water, the hardness is least in the outer portion and increases rapidly toward the center (Fig. 6).

4. When cracking takes place, lines of cracking cut equi-hardness curves almost orthogonally. The form of equi-hardness

72	75	76	78	78	75
78	75	90	88	79	77
75	88	95	91	87	86
75	90	93	93	90	85
79	90	92	89	85	82
75	78	86	82	77	75

Fig. 6

curves is elongated in a direction normal to the line of cracking (Figs. 7, 8, 9).

5. In the cubes, the equi-hardness lines become roughly circular or elliptical at a short depth from the surface.

6. Cracking occurs in most cases, when the temperature of the specimens falls nearly to that of the bath.

7. The hardness does not increase appreciably, so long as the quenching temperature is below the Ac_1 point. When the temperature increases beyond the beginning of the Ac_1 range, the hardness rapidly increases, reaches a maximum at about 820 degrees Cent. and afterward slightly decreases.

The explanation of these facts is as follows:

According to the theory of quenching, the A_1 transformation is a stepped change consisting of

$$\text{austenite} \rightarrow \text{martensite} \rightarrow \text{pearlite}.$$

But with regard to the volume per unit of mass, the relation is,

$$\text{martensite} > \text{pearlite} > \text{austenite}$$

for martensite is known to exist in a more dilated state than pearlite, and the latter in a more dilated state than austenite, as is seen from the expansion-temperature curves[11] at high tempera-

11. K. Honda, *Science Reports*, 6.

tures. Hence in the A_1 range, during slow cooling, the elongation is a differential effect of the expansion due to austenite→martensite, and of the contraction due to martensite→pearlite; during slow heating, the contraction is a differential effect of the expansion due to pearlite→martensite, and of the contraction due to martensite → austenite.

In quenching experiments, the rates of cooling in the outer and inner portions of the specimen differ considerably from each

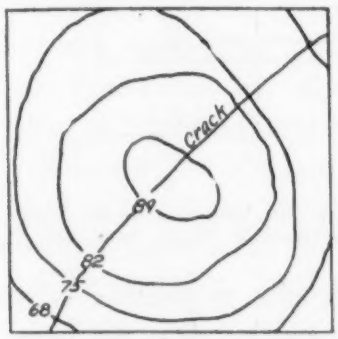


Fig. 7—Equi-hardness lines of a 1.0% Carbon Steel Quenched in Oil from 810 Degrees Cent.

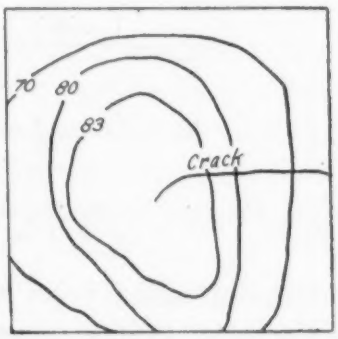


Fig. 8—Equi-hardness Lines of a 0.91% Carbon Steel Quenched in Water from 880 Degrees Cent.

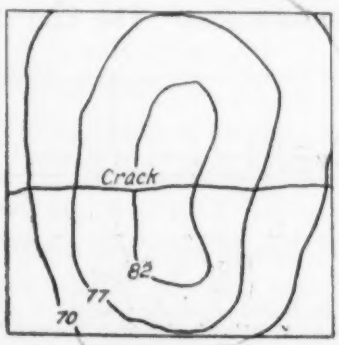


Fig. 9—Equi-hardness lines of 1.0% Carbon Steel Quenched in Water from 870 Degrees Cent.

other. In the outer portion, where cooling is very rapid, not only the second change of the A_1 transformation, martensite to pearlite, is stopped, but also its first change, austenite to martensite, is partially arrested so that this portion contains a certain amount of austenite intermingled with martensite. In the inner portion, the rate of cooling is not so rapid, and hence the austenite is mostly transformed into martensite; but its further transformation into pearlite is arrested. Since the austenitic structure is much softer than the martensitic structure, it is to be expected that the outer portion,

containing a greater proportion of austenite than the inner portion, will be softer than this portion.

If the above view be correct, for a soft quenching, such as quenching in oil from a moderately high temperature, the outer portion may be just fully martensitized, while in the inner portion, the transformation from martensite to pearlite is partial. In this case, the outer portion must be harder than the inner portion, as is actually brought out by experiments. In a somewhat harder quenching than in the last case, the outer and inner portions may possess nearly the same hardness. The fact that above 820 degrees

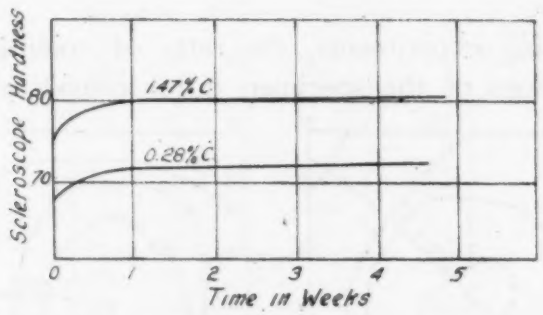


Fig. 10—Showing that a Hard Quenched Specimen at Room Temperature will increase in Hardness with Lapse of Time. Quenched in Water from 880 Degrees Cent.

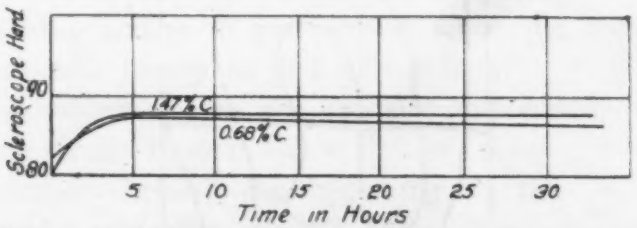


Fig. 11—Showing that Quenched Specimen when Constantly Heated at 100 Degrees Cent. will first Increase in Hardness and then Slightly Decrease. Specimen Quenched in Water at 880 Degrees Cent.

Cent. the hardness gradually decreases as the quenching temperature increases, is explained by the same theory, that is, by a gradual increase of austenite arrested and mixed in martensite.

Several quenched specimens were examined microscopically to see whether any appreciable decarburization actually occurred; but except narrow edges, or at least in portions where hardness was measured, decarburization was negligibly small. Hence the less hardening of the outer portions cannot be explained by decarburization during heating. In many cases, however, it is caused by the arrested austenite during quenching.

The cause of cracking was next investigated in a series of equi-hardness curves for a number of carbon steels quenched from varying temperatures. Since the form of the equi-hardness lines was elongated in the direction perpendicular to the line of cracking (Fig. 7), it is to be concluded that the martensite development is greatest in the elongated central portion and least in the periphery; hence the martensitic expansion in the former portion is much greater than that in the latter portion. The central portion exerts, therefore, a great tension on both sides, this tension causing the cracking of the specimens. This is the reason that the lines of cracking are normal to the elongated equi-hardness curves. Since the difference in the specific volumes for martensitic and austenitic structures increases rapidly as the temperature falls[12], it may be understood why cracking generally occurs, when the temperature of the specimen approaches to room temperature.

Conclusions

Having thus far explained the distribution of hardness and crack lines, the question of how to avoid quenching cracks arises. In quenching practice, it is not necessary to get a very great hardness, except in the case of cutlery. It is also evident from the above investigation that to obtain a martensitic structure, too rapid cooling is unnecessary. In order, therefore, that the specimen may not crack during quenching, but that its hardness be properly developed, quenching must be medium hard, such as quenching in oil from 900 degrees Cent. (1650 degrees Fahr.), in which case the hardness is nearly constant throughout the specimen; hence the stress due to the difference in the structures is small, and consequently cracking cannot occur.

According to the above view, in a hard quenched steel, some austenite remains untransformed at room temperature, at which this austenite will slowly transform into martensite. On the other hand, at room temperature martensite has a tendency further to be transformed into troostite, but its velocity is much smaller than that of austenite→martensite just referred to. The consequence is that at room temperature a hard quenched specimen will slowly

12. K. Honda, *Science Reports* 8, (1919), 186.

increase its hardness with lapse of time. This inference is brought out by experiments[13] (Fig. 10).

If the quenched specimen be constantly heated at 100 degrees Cent. instead of letting it remain at room temperature, the above change from austenite to martensite will be much accelerated, at the same time the change from martensite to troostite will also be accelerated. Hence the hardness first increases, reaches a maximum, and then slightly decreases. As shown in Fig. 11, this conclusion is actually brought out by experiments[14].

What the hell

13, 14. *Science Reports* 9, (1920).

METALLOGRAPHY AND TESTING OF OXYACETYLENE WELDS

By J. R. Dawson

Abstract

This paper deals with the application of oxyacetylene welding to various classes of steel and to cast iron. Photographs are included to illustrate the effect of the process on the structure of metals that are welded. The physical properties of welded metals are discussed and illustrated by typical test results.

The author has emphasized that oxyacetylene welds are quite dependable when the work is done under suitable conditions and with proper supervision. Stress has been laid on the need for testing of the welder's work. The opportunities for saving, that results from greater use of the welding have been mentioned, and a plea made for the application of the principles of heat treating to welding problems, which are of a nature to require metallurgical knowledge.

WELDING is a metallurgical operation. Since we, as steel treaters who devote our experience and thought to proper control of metallurgical practice and correct heat treatment methods, are frequently called upon to decide the suitability of welding applications to production work and repairs of products or plant maintenance, the author ventures to present briefly, results and conclusions arrived at in the course of extensive research in the problems of oxyacetylene welding and cutting.

The extent of the metallurgical features of oxyacetylene welding may well be appreciated from the consideration that molten metal under the gas flame is comparable to the bath of an open-hearth furnace, and is subject to treatments similar to those given the open-hearth bath, such as changes of composition due to oxidation, addition of alloys, and interchange of elements be-

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A paper presented before the annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, J. R. Dawson, is associated with the Union Carbide and Carbon Research Laboratories, Inc., Long Island City, N. Y. Written discussion of this paper is invited.

tween the metal and slag. Furthermore, metal adjacent to the zone of deposited metal is necessarily heat treated to some extent, and throughout all investigations of welds and welding this heat-treatment factor is of importance.

Importance of Competent Welders

The results obtained in fusion welding are quite uniform and dependable when suitable materials are used and the work done by competent welders. The most important element affecting weld quality, is the manner in which the operator handles the work. The following factors are also of importance in securing satisfactory quality of welding:

1. *Selection of men*

Most men of average ability can become good welders. The requirements are honesty, patience, and a reasonable amount of manual dexterity.

2. *Training methods*

Training is obviously of the same importance for this work as for that of other crafts. Mention should be made at this point of the excellent work of the American Welding society committee on training operators.[1]

3. *Supervision*

Those in charge of welding work should understand the properties of the metals being handled and of the welded article, and they should know enough of the details of correct welding methods to judge the quality of the work being done.

To prove the quality of a welder's output, it is only necessary to use the tensile or bend test on a number of specimens made by him, welding materials of satisfactory quality, having been provided. Check-tests of welder's work are of great importance and should be made regularly by competent supervisors who are capable of recognizing the quality of welding.

Until recently, little distinction was made between welding rods and ordinary wire, but the need of suitable, good quality rods, is of first importance, for the quality of the resulting deposited metal is largely dependent upon the rod used.

1. Bulletin of the American Welding Society, May, 1923.

Quality of Welding Rods

Fig. 1 shows welding rod steel that is practically free from nonmetallic inclusions. Fig. 2 is of welding rod steel that is unsatisfactory on account of the large number of nonmetallic inclusions. When the dark areas are examined at higher magnification they are seen to contain small slag particles. Welding rods of quality illustrated by Fig. 2 are quite common but the better quality material can be made and tons of welding rods of high purity are consumed every month. Flame melting tests have been

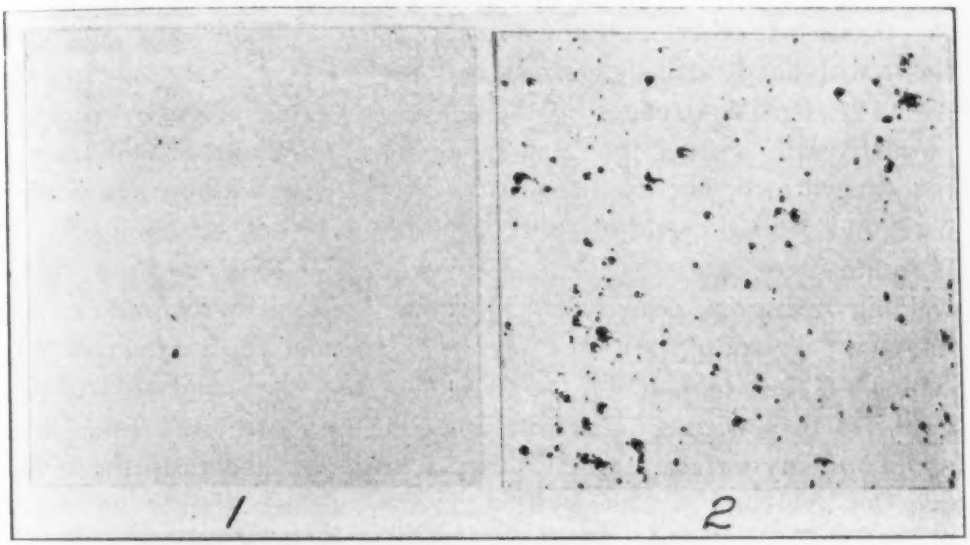

Fig. 1—Photomicrograph of a Polished but Unetched, Good Quality Welding Rod, x100. Fig. 2—Photomicrograph of a Polished but Unetched, Poor Quality Welding Rod, x100.

devised that will discover the steel containing nonmetallic inclusions and dissolved or occluded gases. One such test that is often applied, is to place the welding rod in a horizontal position and pass a welding flame of suitable size over its length at such uniform rate as to melt half way through the rod. It should melt and flow together evenly without boiling or throwing off sparks. If the steel contains gases the metal upon solidifying will be of spongy appearance. The 'dirt' contained in the steel can be observed during the melting, as it reflects more light than the metal and appears as brilliant white spots or lines. When such inferior

rods are used it is difficult to prevent the inclusion of impurities and gas pockets in the weld.

Low-Carbon Steel Welding

At present most steel welds are made with rods of the following composition:[2]

Carbon—Not over	0.06 of one per cent
Manganese—Not over	0.15 of one per cent
Silicon—Not over	0.08 of one per cent
Sulphur—Not over	0.04 of one per cent
Phosphorus—Not over	0.04 of one per cent

Rods of other compositions are also available and some of them will be described later in this paper.

The tensile strength of a double V weld, properly made in ½-inch plate with a low-carbon steel rod is about 52,000 pounds per square inch, but experience has shown that without knowledge, care and skill, a weld of this strength will not be obtained. It is quite necessary that sample welds be tested, because many welding operators permit imperfections in their work and do not know it. A simple test is to place a specimen in a vise with the center of the weld at the top edge of the jaws and to hammer until fracture occurs. Inspection of the fracture will reveal the nature of any defects and by practice and repeated tests the faults may be overcome. The ability of each welder should be tested in this way, or better, by pulling the welds in a testing machine, before he is permitted to do important work. Occasional tests should be required to prove that a proper standard of efficiency is being maintained. This point may be illustrated by results recorded in Table 1, of a series of tests of welds made on consecutive days.

This example is entirely typical of a welder with considerable experience, unknowingly doing poor work and making almost 100 per cent improvement once his mistakes are demonstrated.

A series of experiments were recently carried out to determine the physical properties of weld metal. Blocks of metal were deposited so that test specimens about 4x⅜x1½ inches could be machined out, and the results as shown in Table II were ob-

2. Welding Wire Specifications and Folios, American Welding Society, Bulletin No. 2.

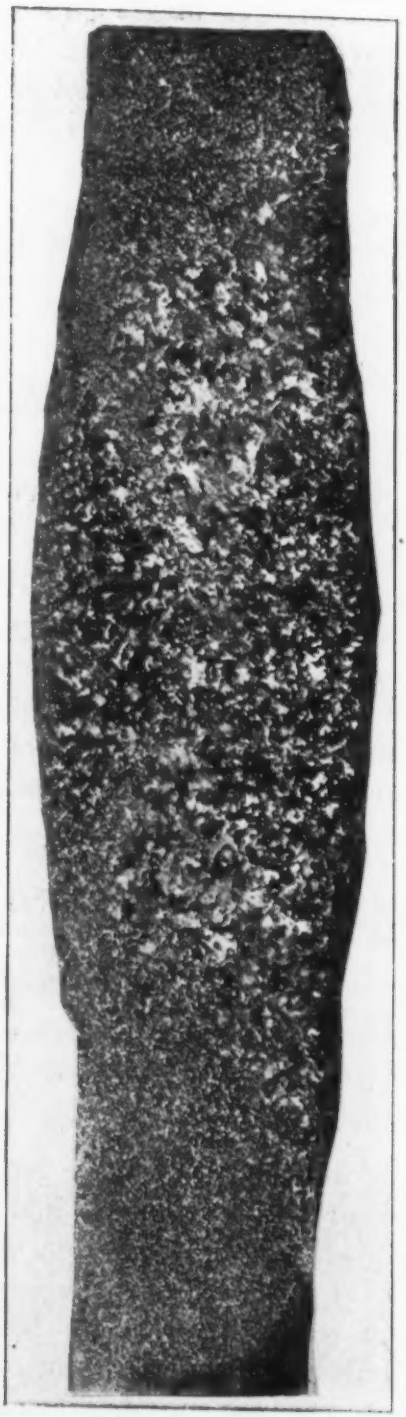

Fig. 3—Macrograph of Double "V" Weld in ⅜ Inch Low-Carbon Steel Plate, Etched with Ammonium Persulphate, x3

tained in testing the untreated material.

In this table the results for tensile strength compare favorably with those obtained in testing annealed low-carbon steel, but the elongation and reduction of area are not so good as in rolled plate. It is of interest to note that in tests of welds made in

Table I

Tensile Tests of Single "V" Welds
Each Value is the Average for 5 Tests

Day Welded	Ultimate Tensile Strength Pounds per Square Inch	Elongation Per Cent In 2 Inches
1st	27,000, equivalent to strength obtained by single riveting	3.2
2nd	37,500	6.5
3rd	43,200	12.4
4th	46,100, equivalent to strength obtained by triple riveting	11.5

similar materials with a given type of rod, that elongation and reduction of area vary with the tensile strength while in rolled material one usually increases as the other becomes less.

In Fig. 3 the darker material near the center is filled-in weld metal whose grains are relatively coarse. The structure of the base metal adjacent to the weld has been coarsened by the high

Table II

Tensile Tests of Weld Metal Deposited with Oxyactelylene Flame

Specimen Number	Size	Pounds Per Square Inch Yield Point	Tensile Strength	Elongation Per Cent In 2 Inches	Per Cent Red of Area
1	1.483 x .366	36,000	49,100	29.0	26.9
2	1.503 x .386	32,300	53,500	36.0	41.0
3	1.507 x .381	37,000	50,800	32.0	35.9
Average		35,100	51,100	32.0	34.6

temperature attained at that point. It may be observed that the structure of a portion of the weld metal and surrounding base metal has been refined when the second side was welded. At a distance from the weld of about 3 times the base metal thickness, a temperature has been reached which was just high enough to refine the base metal grains. This is the point of greatest ductility and of lowest strength of base metal. Tensile test specimens often break in this zone.

Fig. 4 shows the structure of low carbon steel weld metal.

This material is similar in structure to a steel casting, and is practically carbonless. The scattered small black dots throughout the area are believed to be ferrous oxide.

Experiments have been made in annealing low carbon steel welds, in which it was found that a temperature of 1750 degrees

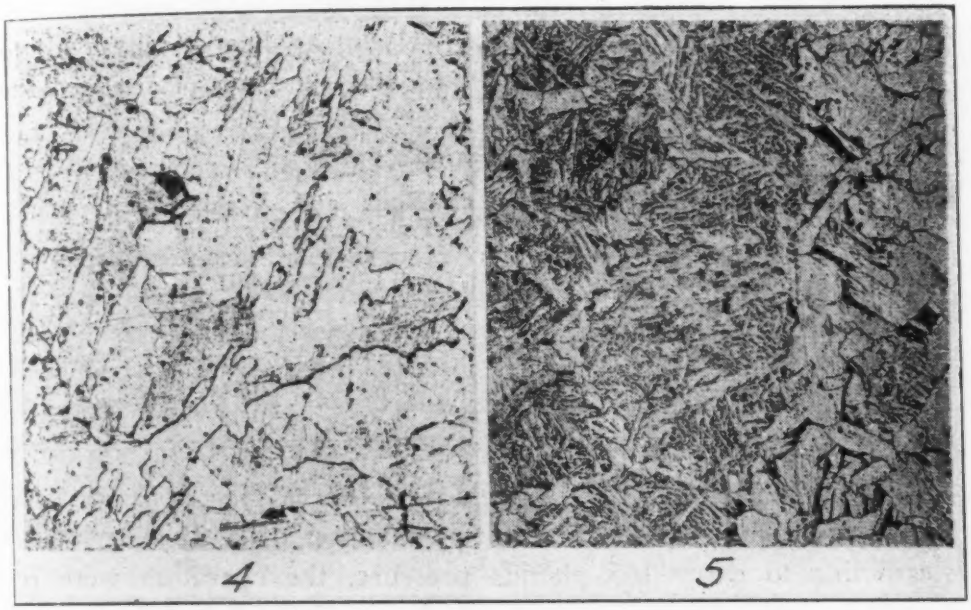

Fig. 4—Structure of a Low Carbon Steel Weld Metal. This Material is similar in Structure to a Steel Casting and is Practically Carbonless. The Small Black Spots are Believed to be Ferrous Oxide, x100. Fig. 5—Structure at Junction of Nickel Steel Weld Metal, at Left, and Coarsened Low Carbon Steel Parent Metal, at Right. This Lacy Structure is Characteristic of a Nickel Steel Weld Metal, x100.

Fahr. was required to refine the grains. This high temperature coarsens the base metal and to obtain good structure throughout the section a second annealing at 1450 degrees Fahr. is required. Annealing does not increase the weld strength but does make some improvement in ductility.

An outstanding feature of recent development in low carbon steel welding is the success attained in welding steel and wrought iron pipe. Until rather recently only a limited amount of steam, oil, gas, and water carrying pipes were welded. Studies have shown that the welding is not only less expensive than other methods of installation in first cost, but that it has a tremendous advantage due to the avoidance of leakage with its attendant loss of product and expense for repair and damage. Because the

screw joint weakens the pipe at the thread, and flanges or caulked joints are loosened by strains or vibration, it is not unusual to have a loss of 10 to 20 per cent of fuel gas or illuminating gas by leakage from lines having such joints. Leaking gas always brings to mind the hazard of carbon-monoxide poisoning. Welded oil carrying lines do not require frequent inspection, and so the need for line walkers is largely eliminated.

The advantages of these pipe welding applications have led to welding of high pressure steam lines and success has attended the

Table III

Chemical Analysis of Rods and Welds

	Per Cent Carbon	Per Cent Manganese	Per Cent Silicon	Per Cent Nickel
Low Carbon Steel Rod	0.07	0.15	.007	
Weld made with it	0.05	0.10	.004	
Medium carbon steel rod	0.24	0.41	.043	
Weld made with it	0.08	0.32	.004	
Nickel steel rod	0.24	0.62	0.21	3.11
Weld made with it	0.12	0.36	0.03	2.83

efforts. The basis of this success was the testing of work done by the welders. Before a recent installation of a 21-inch welded steam line to carry 165 pounds pressure, the operators were required to weld around a joint which was later tested by cutting in strips across the weld and breaking it in the tensile machine. A surprising result of this test was that the specimens from the bottom of the pipe where overhead welding was required, were better than from other parts of the pipe. The explanation for this is that a relatively small flame must be used for overhead welding and better opportunity was given for careful work and the avoidance of overheating.

Medium Carbon Steel

It is sometimes recommended to weld medium carbon steel with medium carbon steel welding rods but tests as to strength of weld have shown no advantage over welds made with low carbon rods. As illustrated by Table III, the weld metals obtained from the two rods are of practically the same chemical composition.

The loss of carbon is less with the nickel steel and a stronger weld is obtained when it is used. Fig. 5 illustrates the structure

at the junction of nickel steel weld metal, at the left, and the coarsened low carbon steel parent metal, at the right. This lacy structure is characteristic of a nickel steel weld metal. The junction of two types of structure affords an excellent opportunity to observe the method of intermingling of the two metals by the growth of grains across the boundary.

An objection sometimes aimed at welding is: "Well, the tensile strength is all right but the elongation and contraction are low. What will happen when the weld is subjected to bending and alternating stresses?" The average tensile strength of a well made low carbon steel weld is 52,000 pounds per square inch and the average reinforcement is 20 per cent of the plate thickness, so that the available strength of the joint is 60,000 pounds per square inch of plate section. Most low carbon steels are of less strength. If greater weld strength is desired rods of special composition will produce a weld of 58,000 to 60,000 pounds per square inch of plate, and reinforcement will still further increase this figure to about 70,000 pounds per square inch as referred to base metal thickness. Inherently and by reason of the reinforcement, the weld is also stiffer than the plate metal, so that bending stresses are resisted by the weld and bending occurs in the adjoining metal as illustrated in Fig. 6.

These are single "V" welds in ½ inch low carbon steel plate with the standard low carbon steel welding rod. These 1½ inch wide strips were cut from the welded material and bent at the weld by holding in a vise and striking with a sledge hammer. When this bending was carried as far as possible the specimens were brought to the form shown by steam hammer blows. At first, most of the bending was outside the weld but in this case the heavy blows forced the weld to bend to about a ½-inch radius. In a recent valuable paper [3] describing extensive investigations of endurance properties, it was pointed out that endurance properties are definitely related to tensile strength and that for many uses too much importance has been given to ductility. Increase of tensile strength increases the resistance to fatigue failure. Since the weld can and should be made of greater strength than the metals joined, high resistance is offered to alternating and

3. D. J. McAdam, Jr., American Society for Testing Materials, *Proceedings*, 1923, entitled "Endurance Properties of Steel: Their Relation to Other Physical Properties and to Chemical Composition."

other stresses and should the use require ductility it will be obtained from the material surrounding the weld.

As has many times been pointed out, a weld is only a casting, but there are certain differences from most castings. The weld metal is molten only an instant. Time is given for impurities to float to the surface, and then the blowpipe is advanced and the

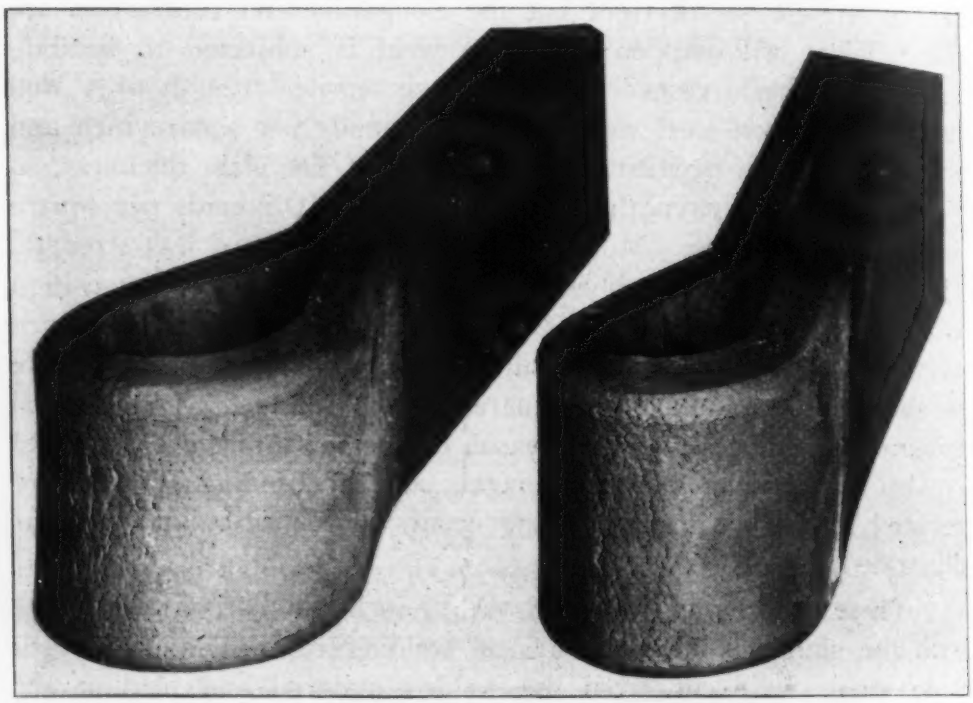

Fig. 6—Bending Tests of Welds, Actual Size.

metal freezes. The volume of melted metal is so small that solidification occurs before extensive dendritic structures have had time to form, and therefore some of the objectionable features that are associated with steel castings are not encountered in welds.

Those engaged in the art of heat treating are familiar with the effects of sonims and other imperfections on the quality of the steel they use. The welding engineer is also deeply concerned with the problem. The quality of base metal has a decided influence on the weld obtained. There is a certain amount of intermingling of the base metal and filling rod metal, as both are melted together to form the weld. If slag particles of the base metal are numerous there is a tendency for films of oxide to be formed

around the grain boundaries at the junction of weld and base metal, and also at times lines of oxides are found deposited in the high temperature ferrite grain boundaries of the base metal adjacent to the weld but not melted during welding. This oxide was no doubt dissolved by the metal when at high temperature and rejected to the grain boundaries during cooling. Steel containing gases is especially objectionable when used in the form of sheet metal for welding. Porosities are formed by gases that escape during solidification of the melted steel.

Steel Forgings

It is impossible to formulate rules for welding of steel forgings that will be of general application. The following must be considered:

1. The chemical composition
2. The stresses the metal at the weld must endure
3. Possibility of heat treatment

It should be kept in mind that the metal near the weld is heated and the extent of the effect depends upon the temperature attained and the length of time at that temperature. This heating may create a structure less desirable than the original and will certainly produce a difference between the structures of the weld and surrounding metal, and the remainder of the forging. If the weld is required at a point where only small stresses will be applied to the part in service, welding of course is permissible. If suitable heat treatment can be economically applied to the welded forging structural uniformity will be regained.

A use of the oxyacetylene process that is becoming of increasing importance is the cutting of steel forgings, by which, in a wide variety of instances great savings are made by reduction of the amount of machining necessary to complete the part.

Fig. 7 is a macrograph of section of a forging 5 inches thick after cutting with the oxyacteylene cutting blowpipe. The structure of the darkened area on upper side of picture, has been altered by the heat incident to cutting. This area is less than 3/16 inches in depth. Further investigation of this material shows that annealing removes the difference of structure. Researches have

developed the following information:

1. Steel containing less than 0.40 per cent carbon can be cut accurately and smoothly without difficulties of any sort, and with great saving of time and expense.
2. Preheating to about 800 degrees Fahr. is advisable when the carbon content is above 0.40 per cent, for if the steel happens to be of poor quality small cracks may occur unless this precaution is taken.

High Carbon Steel

As the carbon content of steel becomes greater the metal is more easily overheated with attendant difficulty in obtaining high

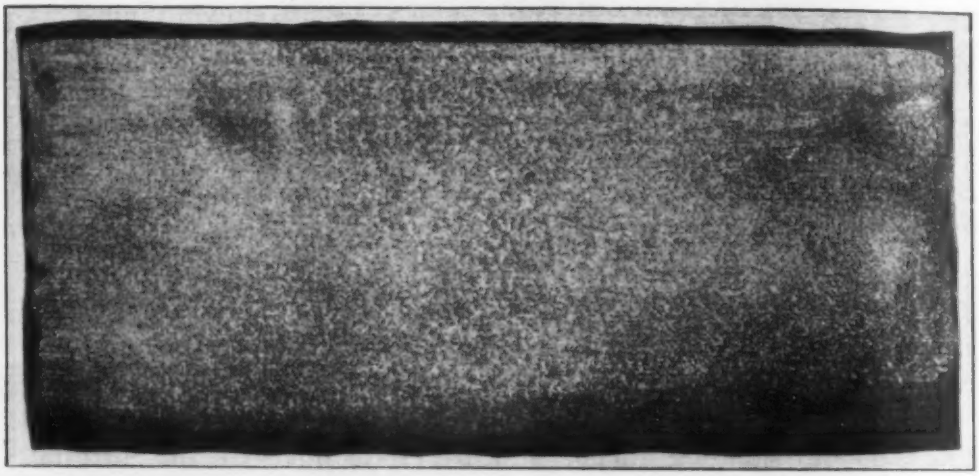

Fig. 7—Steel Forging Cut by Oxy-acetylene Blowpipe, taken at nearly Full Size. The Structure of the Darkened Area on Upper Side has been Altered by the Heat Incident to Cutting.

strength welds. A capable welder will not 'burn' steel containing 0.90 per cent or less carbon. Fig. 8 shows the structure of a 1.10 per cent carbon steel that has been welded. The 'burnt' area shown was on the bottom side near the weld. The black lines at the grain boundaries show the burning. They are really cracks. The top of the specimen was enveloped by the welding flame and protected from oxidation.

An important welding application to the higher carbon steels is filling up to original form of areas that have been worn. By correct selection of welding rod, the repaired portion is frequently made more resistant to wear than the original metal.

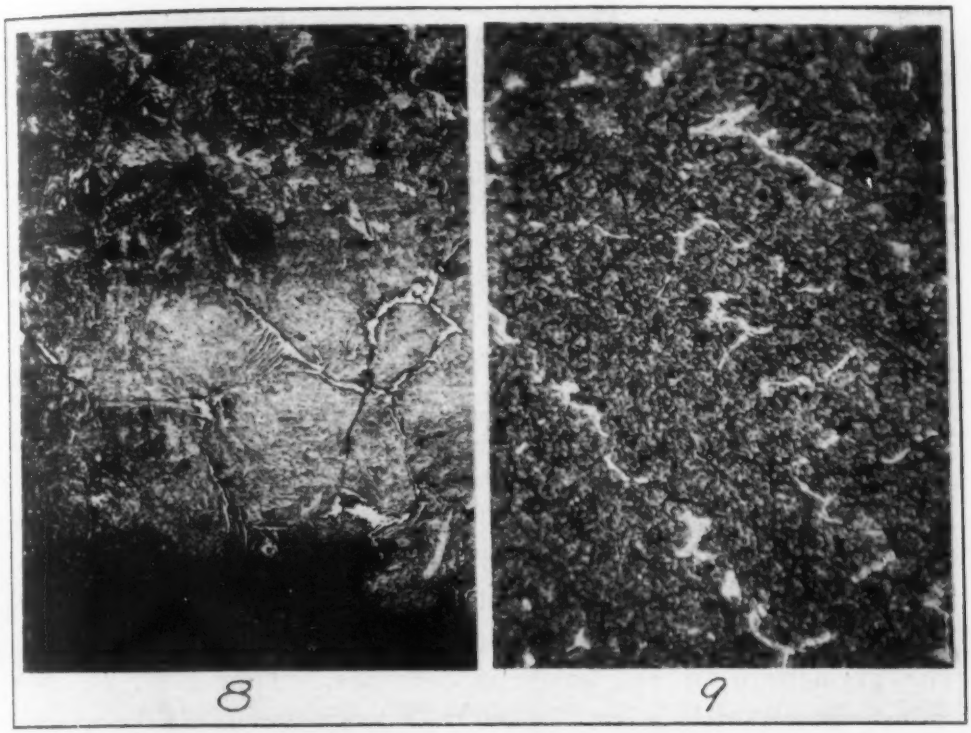

Fig. 8—"Burnt" High Carbon Steel, Near Weld. The Burnt Area Shown at the Bottom of the Photomicrograph, x100. Fig. 9—Welded High-Speed Steel Tool Tip, x435. Most of the Carbide Particles are Small and Widely Distributed.

From the standpoint of welding, alloy steel may be classed with forgings. There are many instances where the process may be used to advantage and others where it would be a mistake to employ it. The use of the steel part, its composition, adaptability to heat treatment, the point at which welding is applied, etc., all have a bearing on the decision of suitability for welding. In many cases a rod of the same composition as the steel to be welded may be used to advantage.

High-Speed Steel

It is sometimes practicable to make special high-speed tools by the oxyacetylene welding process. Where extra strength of tool is required or a type of tool that is used only occasionally is needed, a mild steel shank may be machined out at the end, a carborundum mold placed around it and high-speed steel rod of usual composition melted in by the blowpipe. Such a tool may be

forged, quenched and tempered.

Fig. 9 shows the structure of the metal in a welded high-speed tool tip. Most of the carbide particles are quite small and widely distributed. The ground mass appears to be troostite. Traces of austenitic grain boundaries obtained in hardening still remain in the tempered tool.

Manganese Steel

So far as is generally known, welding of manganese steel has never been thoroughly investigated. The following photomicrographs will serve to give an idea of what occurs when welding is done. Fig. 10 shows the structure of weld metal obtained. It is made up of large grains of dendritic form. The structure shown in Fig. 11 is of the base metal 1/8 inch from the weld. The heating of the metal has caused marked grain growth to occur. Fig. 12 is of same location as Fig. 11, but at higher magnification. The grains are of martensitic appearance. Thin films of iron or manganese carbide can be seen between some of the grains. Fig. 13 shows the structure of the weld metal. Grains that appear to be martensite are surrounded by carbide films, and splotches of carbide are scattered throughout the section. Fig. 14 is of weld metal after heating to 1050 degrees Cent. and quenching in water. Carbides are absorbed, large grains have been broken up and much of dendritic structure removed.

The valuable properties of manganese steel are developed by quenching from a high temperature which produces an austenitic structure in which the grains should not be large. The austenitic manganese steel is easily converted to a martensitic condition. Relatively slight cold work as in the passage of locomotive and car wheels over a manganese steel frog will harden the stressed surface and not affect the remainder of the material. As the surface wears away new metal is stressed and hardened. The body of the metal then is strong and tough and wearing surface hard. It is also more susceptible to heat treatment than other steels. This is illustrated by the rapidity of grain growth, and the ease of formation of martensite and carbides.

Welds made in 3/8 inch thick manganese steel with manganese steel rods containing 1.25 per cent carbon and 13.00 per cent

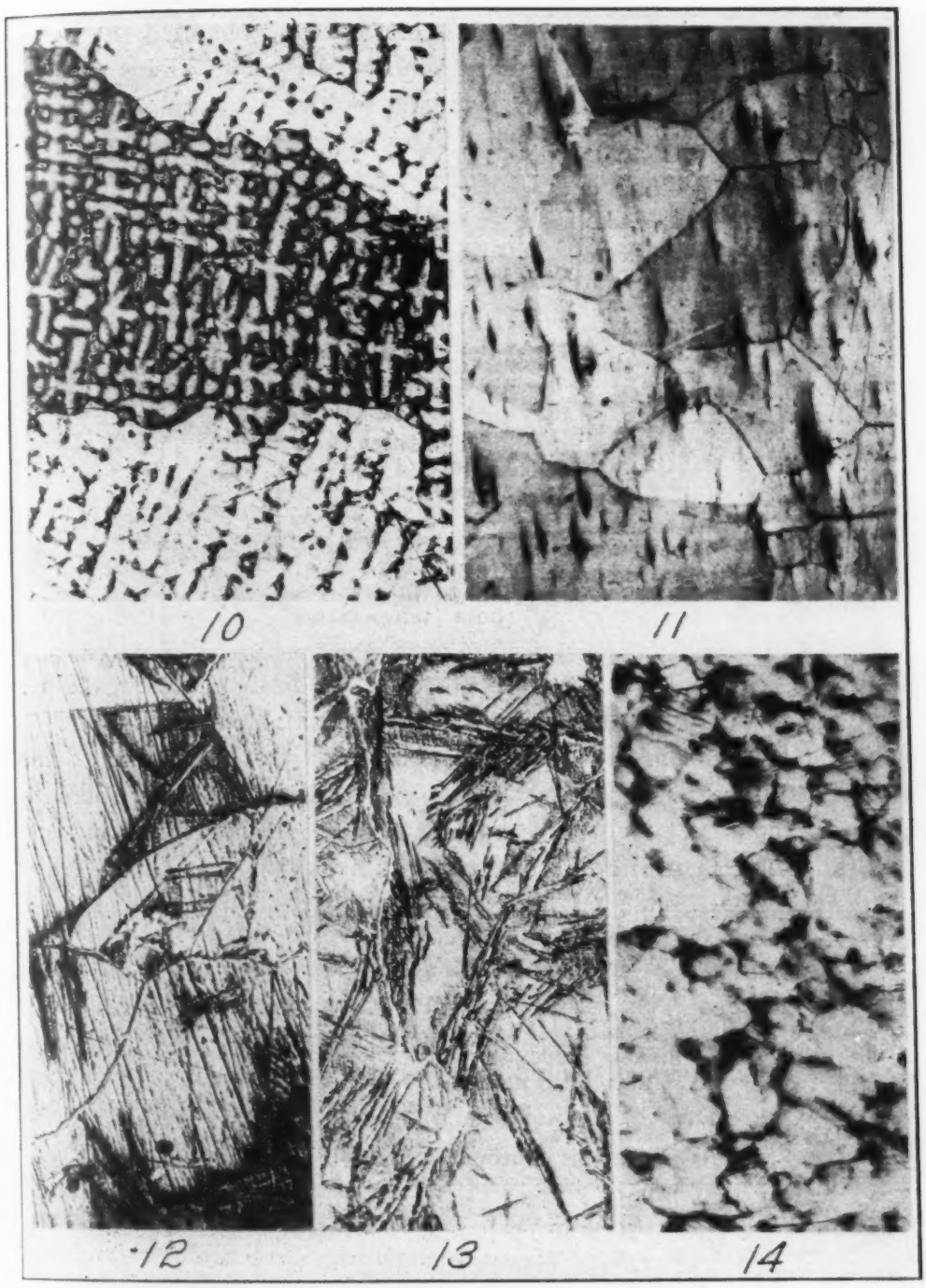

Fig. 10—Manganese Steel Weld Metal, x100, Showing Dendritic Formation. Fig. 11—Manganese Steel Base Metal, Near Weld, x50. The Heating of the Metal has Caused a Marked Grain Growth. Fig. 12—Same as Fig. 11 at, x425. The Grains are of Martensitic Appearance. Fig. 13—Manganese Steel Weld Metal, x425. Grains Appear to be Martensitic Surrounded by Carbide Films. Fig. 14—Heat Treated Manganese Steel Weld Metal, x50. Quenched in Water from 1050 Degrees Cent.

manganese, were tested by clamping in a vise and bending by hammering. The results recorded in Table IV were obtained.

These foregoing tests and photomicrographs indicate that where strength and resistance to shocks are required, the entire weld containing article of manganese steel should be heated to 1050 degrees Cent. and quenched in water. Evidently 1000 degrees

Table IV
Bend Tests of Welded Manganese Steel

Test	Kind of Flame	Heat Treatment	Angle of Bend Before fracture
1	Excess Acetylene	As welded	Zero degrees
2	Neutral	As welded	25 degrees
3	Neutral	One-half hour at 1000 degrees Cent. Quenched in water at room temperature	75 degrees
4	Neutral	Same as 3. Then ½-hour at 1050 degrees Cent., again quench in water at room temperature	95 degrees

Cent. is not high enough temperature for best results. Molten manganese steel absorbs carbon very readily and the elimination of carbides and formation of austenite become more difficult as the carbon content increases. It is the practice of many welders to use an excess acetylene flame for manganese steel welding, but the neutral flame is preferable. The analyses shown in Table V in-

Table V
Manganese Steel Analyses

Kind of Flame	Material	Per Cent Carbon	Per Cent Manganese	Per Cent Silicon
Neutral	Welding rod	1.10	11.50	.08
	Weld metal obtained	1.00	9.60	.05
Excess acetylene	Welding rod	1.17	15.62	0.52
	Weld metal obtained	1.52	13.48	0.21

dicate the effect of welding on the composition of manganese steel.

Since the best properties of manganese steel are not obtained with less than 11.00 per cent manganese the rod should contain not less than 13.00 per cent manganese to compensate for the 2 per cent that is lost during the welding operation.

The addition by welding of manganese steel to other steels

is not satisfactory, for at the weld junction there is diffusion between the weld metal and the base metal and a gradient of manganese content from about 11 per cent to less than 1 per cent will be formed. Some of this junction zone will be weak and brittle, regardless of the treatment applied. For satisfactory results in welding manganese steel, the following should be kept in mind:

1. A neutral welding flame should be used.
2. Welding rod should contain at least 13.00 per cent manganese.
3. The entire welded part should be quenched from 1050 degrees Cent. in water, in cases where service requires high strength and resistance to shocks. Where service requires only compressive strength or resistance to wear, heat treatment is unnecessary.
4. Red hot manganese steel is very brittle and articles during welding should be supported in such a manner as to avoid setting up strains that might cause cracking.

Cast Iron

One of the important applications of oxyacetylene welding is the repair of cast iron parts. The principal reasons for the wide use of this method are:

1. The joint obtained is of high quality.
2. The weld and adjoining metal are machinable.
3. The welding repair, in addition to costing much less than a new casting, is usually important because of the time saved. Frequently a weld can be made and the broken part placed in operation in a fraction of the time required to secure a new part. Many foundries are enabled to hold to high rate of production and efficiency of operation because of the aid of oxyacetylene welding in reclaiming defective castings. This is a practice which should be highly recommended because quality of welded castings is satisfactory and the operation is without harmful effects.

The macrograph shown in Fig. 15 is of a weld in gray iron. There are no blowholes or oxide films, and the weld metal is less coarse than the original metal. Transverse tests of numerous

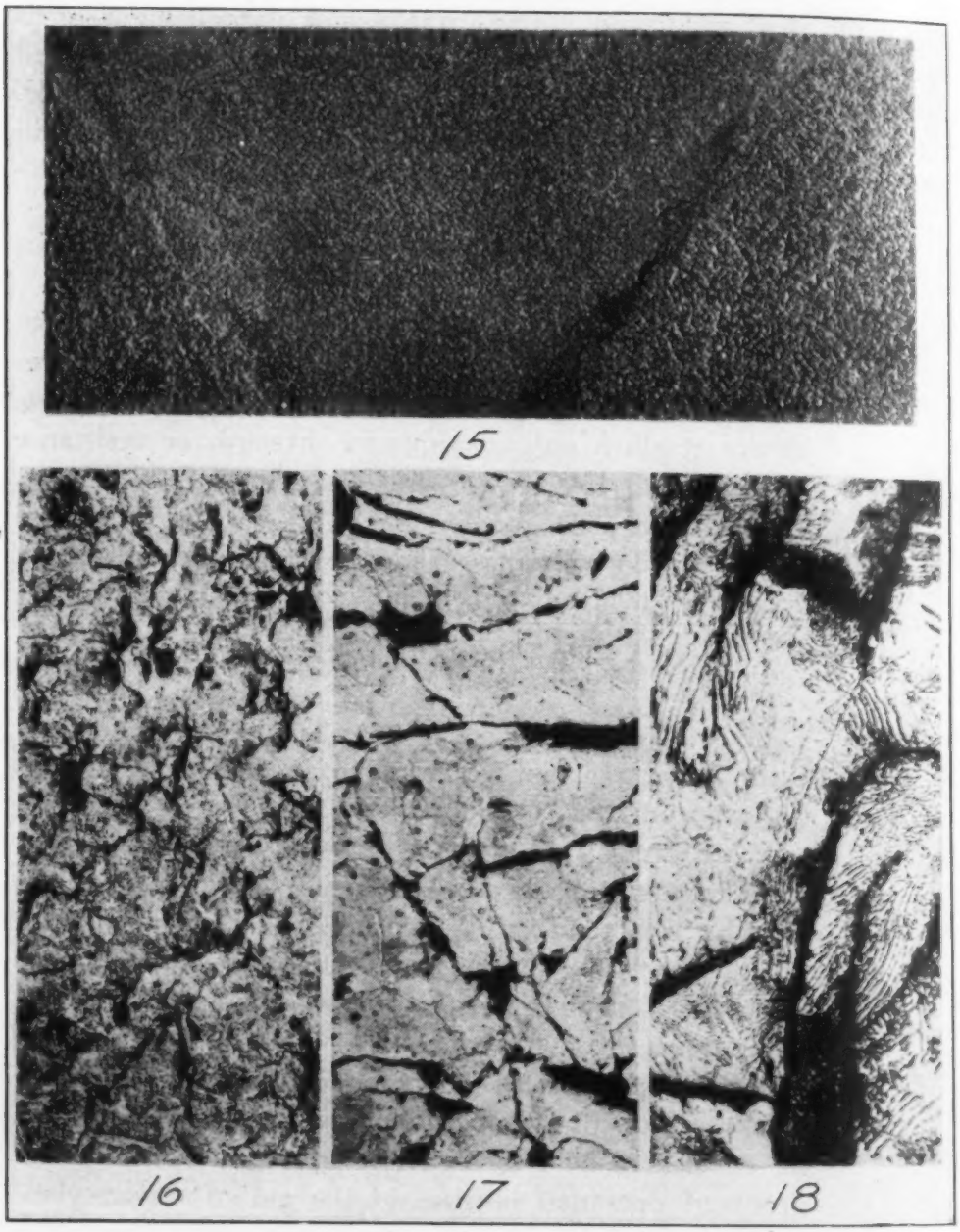

Fig. 15—Weld in Gray Iron, x2. Etched with Copper Ammonium Chloride. Fig. 16—Photomicrograph of Gray Iron Weld Metal, x100. Fig. 17—Photomicrograph of Gray Iron Casting, x100. Fig. 18—Photomicrograph of Gray Iron Weld Metal, x425. Showing Graphite, Lamellar Pearlite and Ferrite, There Being No Free Cementite.

cast iron welds show that it is difficult to cause the break to pass through the weld, which proves that the weld is stronger than the original metal.

The reason for greater strength in the weld may be explained by reference to Figs. 16 and 17. The graphite in the original metal is in the form of large plates or flakes which weaken and embrittle the cast iron. The graphite in the weld is of smaller amount and in smaller plates more rounded in form. The weld also contains a greater proportion of pearlite. Fig. 18 shows the weld metal structure in greater detail. It is made up of graphite, lamellar pearlite and ferrite, there being no free cementite.

The obtaining of good quality, machinable welds requires the use of knowledge gained perhaps in other phases of heat treatment. The hardness of carbon steels is profoundly affected by the rate of cooling and the same is true of cast iron. Provision must be made for slow cooling. Burying in lime or sand is an aid. If the weld is small and the part welded large, heat will be conducted rapidly away from the weld and chilling will occur and some preheating is frequently necessary to avoid this rapid cooling.

An important factor of successful cast iron welding is the employment of correct preheating. Where the parts are free to expand, preheating is unnecessary. Welding of a broken lug is an example of repair in which preheating is not required. Where the weld is surrounded by metal the expansion due to local heating will cause cracking. The same rules as apply in other heating should be employed. Heat slowly and uniformly, make the weld and cool very slowly. In some cases where the part contains sections of widely different area, welding should be followed by a second heating to a uniform temperature before cooling is begun.

Other important considerations are the use of correct welding rod and suitable flux. The influence of the various elements of gray iron composition are fairly well understood. To avoid hardness of weld metal, cast iron welding rods should be of high silicon content, and sulphur should be relatively low. Thus, graphite is precipitated rapidly and free cementite avoided. A proper flux combines with the slag, which is viscuous due to a high proportion of silicon oxide, and forms new slag that is thin, easily fusible, and readily floated to the surface of the weld. The cause of most blowholes in cast iron welds is the failure to float minute impurities to the surface. Careful microscopic examination

will show that where blowholes are permitted to form, a slag particle is the root of the evil.

Brazing of cast iron with manganese or Tobin bronze is meeting with increased favor. The advantages of this method are:

1. The parts can be joined at lower temperature than is required for welding with cast iron rods. Therefore brazing requires lower temperature preheating.
2. The joint obtained is stronger than the cast iron.

The methods of preparing cast iron for brazing are similar to the preparation for welding. Flux is used to clean the surface and when the cast iron is heated to a dull red color the braze can be made and a good junction obtained.

Various Welding Applications

White iron also can be satisfactorily welded. Welding rods of white iron composition should be used. Because of the brittleness of white iron, and its greater shrinkage than gray iron, even greater preheating precautions are required for white iron than for gray iron.

In addition to the uses to which reference has been made, oxyacetylene welding is successfully applied to the following metals: aluminum, copper, nickel and monel metal, and bronzes and brasses. Malleable iron should not be welded, but can be brazed successfully.

Conclusion

It has been the purpose of this paper to point out briefly some of the applications of welding and to emphasize the dependability of the process. A study of the rapid growth of welding and increase of its application leads one to the conclusion that the opportunities it offers for increased industrial efficiency are great.

A knowledge of metallurgy and heat treatment is necessary for proper understanding of the art, and members of this Society are especially fitted to appreciate the fundamentals of welding and its application to individual plants. It has been pointed out many times that actual loss results from failure to take advantage of the opportunities offered by this Society to aid in keeping pace with progress in heat treating knowledge and methods, and in the

same way it is unquestionably true that present day industries can ill afford to neglect the savings offered by modern welding methods.

Although it is true that heat treaters might well make greater use of welding, to an even greater degree the welding industries are in need of the interest and advice that you gentlemen are able to give, on account of your knowledge of the action of metals under high temperatures.

THE SEASONING OF STEEL

By W. P. Wood

Abstract

It is the custom of some manufacturers to age castings and forgings for a period of months in order to produce a more ductile metal. Speculation as to what other effects such a seasoning might produce in steel and iron lead to the test which is described in the paper. Briefly speaking, the experiment consisted in comparing the tensile properties of several varieties of unhardened steel before and after an exposure of one year to the varying temperature of the atmosphere. As might be expected, there was noted an increase in ductility and further than that, the alloy steels carrying noncarbide forming special elements such as nickel and silicon appeared to exhibit a decrease in tensile strength. The writer is not presenting this paper as a finished piece of work, but largely to ascertain through discussion or comment whether there is any unpublished data which may have a bearing upon the question in hand.

CONSIDERABLE interest has been evinced recently in what might be termed the low temperature phenomena of iron and steel. By this is meant any changes which take place in the metal after it has been cooled either rapidly or slowly to a temperature well below the familiar critical ranges. That many such changes do occur has been demonstrated by several investigators and this work was thoroughly summed up by Dr. Jeffries[1].

The writer would suggest that those interested in this matter, refer to Dr. Jeffries article as a starting point.

It has been a generally accepted opinion that these changes are the result of an attempt on the part of the metal to reach a state of equilibrium after heat treatment. The physical evidences of these changes include a gradual evolution of heat, dimensional changes, changes in physical properties, and so forth. It should

1. *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. LXVII, page 56.

A paper presented at the annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, W. P. Wood, is assistant professor of chemical engineering, University of Michigan, Ann Arbor, Michigan. Written discussion of this paper is invited.

be made clear that most of the changes have been noted in recently hardened steel rather than steel in the annealed condition.

It, however, would be hard to say just where this readjustment ceases, because we are limited by the delicacy of the means of measurement at our command.

The writer's interest was first aroused in this connection upon learning that it is the custom of some manufacturers to "season" iron and steel, particularly castings, before or after the final shaping and heat treatment. Probably the best example of seasoning is found in the manufacture of gauge blocks. Here, one of the absolute essentials is permanence of dimensions, and some form of seasoning is the only means which will bring this condition about in the metal. In general an artificial seasoning treatment involves alternate exposures of the metal to high and low temperatures within the range —10 to 212 degrees Fahr. H. J. French[2] has given a clear description of some seasoning treatments carried out at the U. S. Bureau of Standards. One striking thing about these treatments is the rather elaborate procedure and the length of time which is required to produce a state of rest in the steel. One point of interest which Mr. French mentions is the fact that the seasoning treatments do not affect all steels in the same degree. One also would infer from his results that permanence is more quickly secured in a steel carrying a high chromium content.

There seems to be no available data concerning the effect of seasoning upon all the physical properties of steel. Reinhardt and Cutler[3] found that the ductility of a steel carrying 0.49-0.55 per cent carbon was distinctly improved upon resting the heat treated steel at room temperature for various lengths of time subsequent to machining. Such a treatment constitutes a type of seasoning. Reinhardt and Cutler note a tendency to an increase of tensile strength while the ductility is increasing. This effect was not very marked however.

In order to satisfy his curiosity as to the effect of alternating temperatures over the range mentioned, upon some types of steel, the writer carried out the experiment which is reported in this paper. He has hesitated somewhat in presenting the results ob-

2. *Chemical and Metallurgical Engineering*, Vol. 25, No. 4, page 155.
3. *Bulletin*, American Institute of Mining and Metallurgical Engineers, No. 151, page 1091.

tained, for they seemed most peculiar and his main purpose in now presenting them is to ascertain through discussion and criticism whether or not there is any positive evidence which will settle the question one way or the other. If the physical tests had been made with less care the question would probably not be worth considering.

Procedure

Simply stated, the experiment consisted in making tensile tests upon several steels before and after an exposure of 1 year

Table I
Steels Used in Seasoning Test

Letter	Type of Steel	Analysis— Carbon Per Cent	Silicon Per Cent	Manganese Per Cent	Sulphur Per Cent	Phosphorus Per Cent	Chromium Per Cent	Nickel Per Cent	Vanadium Per Cent	Tungsten Per Cent
A	S.A.E. 1010	.05-.10	.....	.30-.60	<.05	<.045	.....	.....	.....	.....
R	S.A.E. 1080	.75-.85	.....	.25-.50	<.05	<.04	.....	.....	.....	.....
J	Nickel	0.29	.....	0.55	0.035	0.04	.....	3.48	.....	.....
X	Chrome-Nickel	0.39	0.20	0.62	0.017	0.012	0.75	1.43	.....	.....
F	Chrome-Vanadium	0.30	.....	.....	.....	.....	0.95	.....	0.15	.....
S	Silico-Manganese	0.53	1.87	0.75	0.016	0.017	.....	.....	.....	.....
T	High-Speed	0.65-0.70	0.2-0.3	0.2-0.3	.....	.....	2.90-3.10	.....	0.95-1.05	17.50-18.50

to the varying temperatures of the atmosphere. The range of temperature variation was from about —10 to 100 degrees Fahr. The steels tested, with an indication of their analyses may be found in Table I. The steels used in this investigation were in the unhardened or "as received" condition. All samples were given a brief normalizing treatment to relieve strains. The relative conditions of the metal may be noted from the original tests in Table II.

The steel (which was 3/4-inch round bar stock) was cut into 7-inch lengths which were machined to the shape of standard test pieces. The diameter was left a trifle greater than the required 0.357 inch, the final finishing being done with a file after the normalizing treatment. In this way it was hoped that machining strains might be eliminated. Two of the finished specimens of each type of steel were pulled immediately and the rest were placed in shallow pans of cylinder oil which were located upon the roof of the chemistry building at the University of Michigan. The

pans of oil were covered by a wooden shelter which resembled somewhat an old fashioned chicken coop. By this means, water was prevented from directly entering the pans, but they were freely exposed to the atmosphere, and to the sun during a large part of the day. Enough samples were provided so that a few could

Table II

Results of Seasoning upon Physical Properties of Steel

Steel	Time of Test	Tensile Strength Pounds per Square Inch	Elongation Per Cent 1.4″ gauge	Reduction of Area Per Cent
A	Original	48,950	40.0	.....
1010		50,000	35.8	67.2
	After 8 months	51,500	34.4	69.6
		51,000	36.0	68.2
R	Original	120,000	12.1	.....
1080		120,000	10.7	.....
	After 1 year	115,600	15.2	19.0
		118,400	12.0	19.0
J	Original	75,000	28.6	36.4
Nickel		76,000	27.9	35.0
	After 1 year	66,410	28.0	46.0
		65,820	30.4	46.0
X	Original	89,000	24.3	31.6
Cr-Nickel		90,000	22.2	31.5
	After 1 year	73,700	26.4	50.6
		68,195	28.0	52.9
F	Original	79,300	26.4	60.2
Cr-Va	After 1 year	79,000	36.0	63.6
S	Original	108,500	22.8	29.1
Si-Mn		108,500	22.8	30.3
	After 1 year	93,240	27.2	47.3
		99,450	23.2	39.5
T	Original	112,000	17.9	19.6
High-Speed	After 1 Year	101,800	17.6	24.1
		102,300	18.4	27.4

be pulled at intervals during the year, the last two being pulled one year from the day they were put into the oil.

The testing machine employed was a 100,000 pound universal. A gauge length of 1.4 inches was used in making tests.

Results and Discussion

In Table II may be found the results of the tests. The elastic limit was not determined at first because it was not thought that much change would be apparent in the tensile properties, since previous work had shown that the greatest change might be expected in the ductility. When it seemed after some months that

there were changes taking place in the tensile properties, the elastic limit was determined, but it was too late to make any systematic comparison.

As had been expected, a greater or less increase in ductility was observed, except in the case of the low carbon steel. Very little change of any nature was noted in this steel. The samples which were pulled at the end of a year broke prematurely owing to some flaw in the metal, and manifestly erroneous values were obtained. This test therefore did not extend beyond the eighth month interval. In the case of the 0.8 per cent carbon steel the original reduction of area was so slight that it could not be determined accurately, but after a year the ductility had increased to such an extent that the reduction of area had become 19 per cent.

The result which attracted most attention, was the apparent tendency on the part of some of the alloy steels to decrease in tensile strength. When a close comparison was made it was noted that the steels which tended to show the decrease in tensile strength were the 3½ per cent nickel, the chrome-nickel, the silico-manganese and the high-speed steel. With the exception of the high-speed steel, all these steels are of the type wherein the alloying elements are wholly or partially dissolved in the ferrite. The steels wherein there is the tendency to precipitate carbides did not seem to exhibit marked changes in tensile strength. The high-speed steel was an exception, but it is also true that this type of steel might show a variation from point to point in the original bar.

It would of course be absurd to attempt to develop an explanation of the peculiar behavior of the alloy steels until it had been proven beyond a doubt that the condition exists. It is the writer's intention to carry out another series of tests upon similar samples to obtain more complete information.

Leaving out of consideration the changes in tensile strength, the results of the seasoning upon the steel are what might be expected, namely, an increase in ductility, and the practice of allowing forgings and castings to rest out of doors for a period of several months in entirely justified in that the metal arrives closely at what might be termed a state of equilibrium. Dr. Langenberg[4]

4. *Bulletin*, American Institute of Mining and Metallurgical Engineers, No. 154, page 2935.

suggests that relief of strain is responsible for the increase of ductility but it would seem that there must be some constitutional changes also involved, particularly if tensile strength is affected.

Summary

The natural seasoning or aging of steel is justified in that the ductility of the metal is increased and a state of rest more nearly approached. There seems to be a difference with regard to changes in tensile properties in the behavior of the alloy steels when subjected to natural seasoning. The alloy steels which exhibited the greatest change during this test were those which carried one alloying element in solution in the ferrite.

The whole investigation has raised a question upon which there seems to be very little data, namely, what happens to the physical properties of various steels in service?

CASE HARDENING AND OTHER HEAT TREATMENTS, AS APPLIED TO GRAY CAST IRON

By H. B. Knowlton

Abstract

This paper describes certain experiments which were conducted in heat treating gray cast iron, after a report had been received that gray cast iron could sometimes be "case hardened" with commercial success. Some of the treatments used are similar to those used in case hardening steel. Several other schemes of heating and cooling were employed and are described. It was found that under certain conditions that gray cast iron could be made much tougher in the center and at the same time be given a hard surface.

SOMETIME ago the writer was informed that gray cast iron had been case hardened with commercial success. It was said that a certain firm had measurably increased the strength and wearing qualities of certain gray iron castings, by applying the treatments commonly used in case hardening steel. After this process, the castings were said to be fairly machinable in spite of their increased resistance to wear. The method was considered a success as long as it was applied to castings made by one foundry, but it failed on castings made in another foundry. Evidently the composition of the iron had a great deal to do with the success or failure of the method. The composition, however, of neither was known definitely. Both were simply classified as "gray iron."

The writer does not know how much has been done along this line, but so far has found nothing published on the subject. Consequently the research described in this paper was started. No claim is made that the paper is a complete exhaustive treatise on the subject. It merely attempts to give the status of the writer's research up to the present time. Criticisms, comment and suggestions are invited.

Upon casual consideration, case hardening of gray cast iron did not seem feasible to the writer, and yet it was claimed that

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A paper presented before the annual convention of the Society, Pittsburgh, Oct. 8-12, 1923. The author, H. B. Knowlton, is instructor in metallography and heat treatment, Milwaukee Vocational school, Milwaukee. Written discussion of this paper is invited.

good results had been so produced. A gray cast iron obviously contains more carbon than can be retained in the combined condition. How then, could heating in a carburizing material increase the carbon content of the surface? The writer's only experience with cast iron heated in contact with a carburizing material, consisted in the use of cast iron pots and boxes used as containers in the carburizing process. It is a well known experience that such boxes "grow" on repeated and continued heating. This could be explained on the assumption that any combined carbon originally in the casting, decomposed into free graphite and free ferrite. The writer knew of no reason for assuming that carbon was combining with the iron during this process. Why then, were increased wearing qualities produced by "case hardening?" Was the function of the carburizing material simply to prevent oxidation? Did the quenching treatment merely harden whatever pearlitic areas there were in the original casting, or did some of the carbon in the casting or the carburizing material actually combine with the iron? Was the process similar to the production of chilled castings? If not, could any advantage be claimed for "case hardened" castings over the more common chilled castings? Would they have any advantages over malleable castings? These are some of the questions that the author has started to investigate.

Material

The experiments, herein described, were conducted on samples cut from three sand cast test bars of the following chemical composition.

	Bar No. 1	Bar No. 2	Bar No. 3
Silicon	2.12	2.41	2.49
Sulphur	.073	.073	.107
Manganese	.72	.59	.63
Phosphorus	.367	.635	

These bars were about 1 inch square and were cut into samples ¼ inch thick, with the exception of two samples, hereafter mentioned, which were 3/8 inch thick.

Each sample was given the number of the bar from which it was cut, and in addition was given an individual letter. Thus

samples 1A and 1B are the first and second samples respectively from bar No. 1.

First Series of Tests

Four samples each from bars 1 and 2 were packed in pipes with an ordinary carburizing material such as commonly used in case hardening steel. Two samples from each of these bars were packed in sand in another pipe. The ends of this pipe were protected from outside oxygen by thin layers of charcoal. All of the pipes were sealed with fire clay, placed in a hot furnace and run for three hours at 1700 degrees Fahr. At the conclusion of this heat they were given different treatments described in the data tables. Four other samples from each of these bars were heat treated in the open furnace as described in detail in the tables.

Second Test

After studying the results of these tests another series of tests were run. In this test, four samples from bar No. 3 were packed in a pipe with a carburizing material as before, and run for 8 hours at 1700 degrees Fahr. This pipe was placed horizontally in the furnace. Towards the end of the heat it was noted that the seal was leaking. This may explain some of the results mentioned later. Another sample from bar No. 3 was placed in the middle of a ball of fire clay, and heated in the open furnace for 3 hours at 1700 degrees Fahr. At the conclusion of this time it was allowed to cool slowly in the furnace.

Tests After Heat Treating

After heat treating, the specimens were all cleaned and tested under the Shore scleroscope. The Brinell method was tried on one or two, but it was found that the samples were too brittle for this test. All of them which could be cut with a hand hack saw were so sectioned. They are listed in the data tables as hard or soft on the basis of their ability to be cut with a hack saw. The specimens were placed one at a time in a vice and struck with a 3-pound hand hammer. This was given as a crude test of their toughness. All of the samples were polished and examined under the microscope both before and after etching with picric acid. One sample from each bar went through all of these tests in the

sand cast, untreated condition. The results are given in the data tables, and in the text following. Some of the more interesting microscopic structures were photographed and are shown herewith.

Results

Hardness

It will be noted that all specimens quenched from temperatures above 1500 degrees Fahr. were too hard to saw and showed a scleroscope reading above 55.

Toughness

The most startling thing about all the results was the extreme variation from great toughness to great brittleness on the different

Data Table I
Heat Treatments and Results on Samples from Bar No. 1

Sample	Heat Treatment	Hardness		Toughness
		Shore	Saw	
1A	Sand cast: no treatment	45	Soft	Brittle
1B	Carburized 3 hrs. cooled slowly	40	Soft	Brittle
1C	Carburized 3 hrs. cooled slowly; reheated to 1500°F; quenched in water	65	Hard	Fairly tough
1D	Carburized 3 hrs. quenched in oil directly	75	Hard	Brittle
1E	Carburized 3 hrs. quenched in oil; reheated to 1500°F; quenched in water	68	Hard	Brittle
1H	Heated 3 hrs. at 1700°F in sand; quenched in oil	62	Fairly Hard	Brittle
1I	Heated 3 hrs. at 1700°F in sand; quenched in water	62	Fairly Hard	Brittle
1J	Heated to 1700°F in open furnace; quenched in water	72	Hard	
1K	Heated to 1700°F in open furnace; quenched in oil	68	Hard	Brittle
1L	Heated to 1420°F in open furnace; quenched in water	47	Soft	Brittle
1M	Heated to 1500°F in open furnace; quenched in water	72	Hard	Brittle

specimens. The samples which were tested in the sand cast condition were all easily broken. Unfortunately there were no available means of making quantitative shock tests on specimens of this size. Simply testing by placing the specimen in a vice and hitting with a 3-pound hand hammer, is so crude that it is difficult to describe the results. Suffice it to say that the only ones which could be called tough at all were the ones which were heated in the carburizing

material, slowly cooled, reheated to 1500 degrees Fahr. and quenched in water. All of the specimens so treated showed some resistance to the hammer. The most startling variation was found between specimens 3C and 3G. Both of these were slabs 3/8 of an inch thick from the same bar. Specimen 3G was in the sand cast condition, while 3C had been carburized, cooled, reheated and quenched. The former was broken by one hard blow of the 3-pound hammer, while 3C could not be broken by numerous blows. A 3/32-inch

Data Table II
Heat Treatments and Results on Samples from Bar No. 2

Sample	Heat Treatment	Hardness		Toughness
		Shore	Saw	
2A	Sand cast; no treatment.	45	Soft	Brittle
2B	Carburized 3 hrs. cooled slowly...	39	Soft	Brittle
2C	Carburized 3 hrs. quenched in oil.	77	Hard	Brittle
2E	Carburized 3 hrs. quenched in oil reheated to 1500°F; quenched in water.....	63	Hard	Brittle
2G	Carburized 3 hrs. cooled slowly; reheated to 1500°F; quenched in water.....	55	Hard	Tough
2H	Heated 3 hrs. at 1700°F in sand; quenched in oil.....	55	Hard	Brittle
2I	Heated 3 hrs. at 1700°F in sand; quenched in water.....	55	Hard	Brittle
2J	Heated to 1700°F in open furnace; quenched in water.....	80	Hard	Brittle
2K	Heated to 1700°F in open furnace; quenched in oil.....	70	Hard	Brittle
2L	Heated to 1420°F in open furnace; quenched in water.....	47	Soft	Brittle
2M	Heated to 1500°F in open furnace; quenched in water.....	68	Hard	Brittle

V groove was then ground and filed in this sample, and it was again struck with the 3-pound hammer, but again it failed to break. After several attempts it was broken with a 10-pound sledge. The other samples which received the same heat treatment were only ¼ of an inch thick and consequently were easier broken. The specimens which were simply heated in the open furnace particularly to the higher temperatures, shattered quite easily when hit with a hammer. In some cases a light tap would cause the sample to break into several pieces.

Fractures

The fractures of the original castings were gray. Some of the

specimens quenched from the higher temperatures showed very light fractures which were very coarse grained. As already mentioned these were very brittle. The samples which were cooled slowly all showed gray fractures. Some of the specimens which were carburized, cooled, reheated and quenched showed a difference in the fracture between the center and the outer layer some-

Data Table III
Heat Treatment and Results on Samples from Bar No. 3

Sample	Heat Treatment	Hardness		Toughness
		Shore	Saw	
3A	Carburized 8 hrs. cooled slowly; reheated to 1500°F; quenched in water	70	Hard	Tough
3B	Carburized 8 hrs. cooled slowly	35	Soft	
3C	Carburized 8 hrs. cooled slowly; reheated to 1500°F; quenched in water	70	Hard	Very Tough
3D	Carburized 8 hrs. cooled slowly.			
3E	Sand cast; no treatment	45	Soft	Brittle
3G	Sand cast; no treatment			
3H	Heated for 3 hrs. at 1700°F in clay; cooled slowly	45	Soft	

Note—By the term "Carburized," used in these tables, and in connection, with the photographs, it is meant that the specimen so labelled was heated in a carburiz ng material to 1700°F, without regard to whether the process is true carburization or not.

what similar to the difference between the case and the core of a case hardened steel specimen. The difference was not so pronounced as in the case of steel. The fracture was not as light as some of the specimens quenched from the higher temperatures. Specimen 3C showed a very fine grayish fracture.

Microstructure

In order to understand better what changes actually took place the specimens were examined under the microscope. A few of them are shown here. While these speak pretty well for themselves, especial attention is directed to several things. Figs. 1, 2, 9, 10, 11, 17, 18 and 19 show the three bars in the original cast condition. It will be noted that the structure of each bar contains free graphite, free ferrite, and combined carbon in the form of pearlite. The specimens which were heated in the carburizing material and cooled slowly, show in each instance a

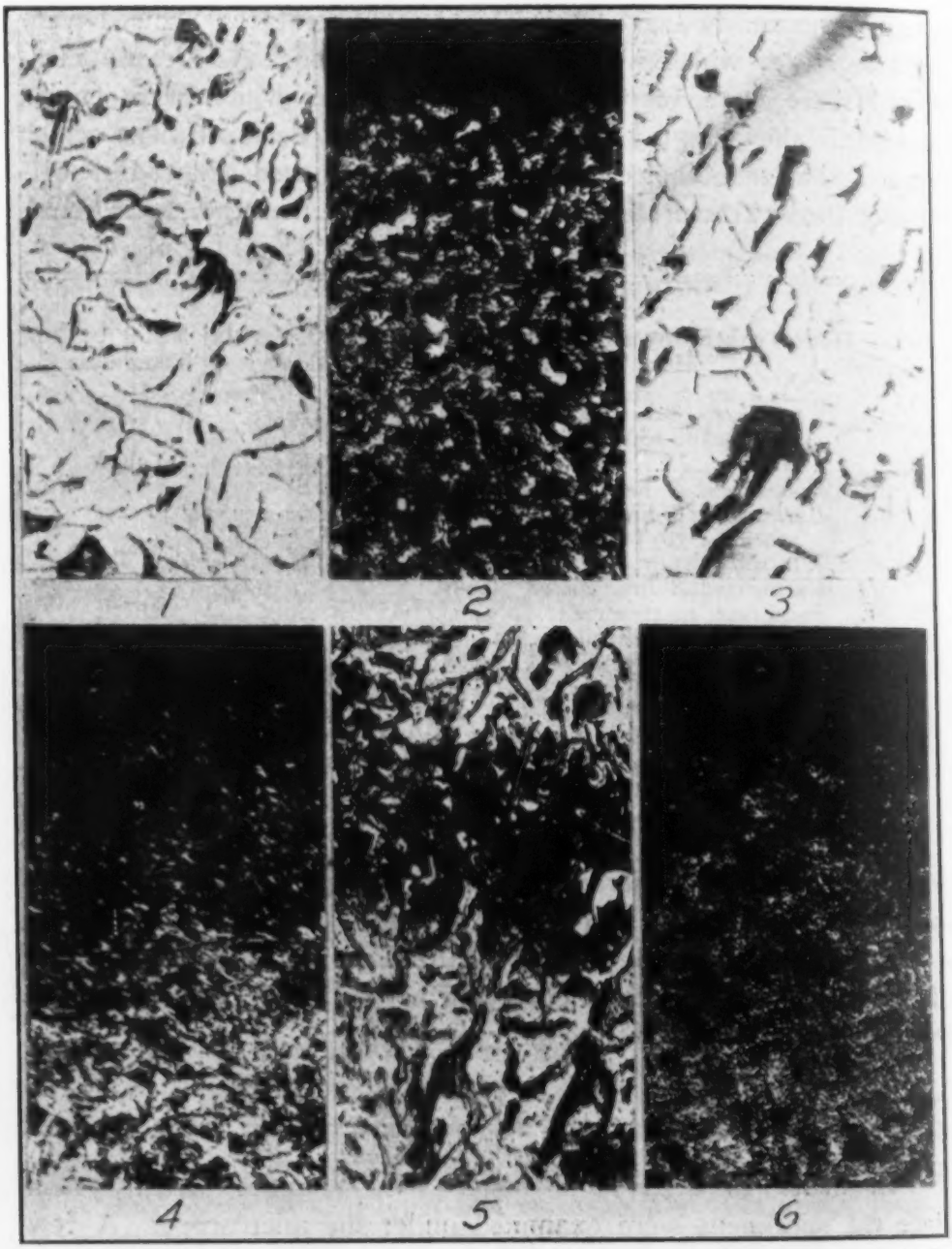

Fig. 1—Specimen 1A as cast, unetched. × 100. Fig. 2—Specimen 1A as cast, etched. × 100. Fig. 3—Specimen 1B, carburized, cooled, center unetched. × 100. Fig. 4—Specimen 1B, carburized, cooled, edge etched. × 100. Fig. 5—Specimen 1B, carburized, cooled, center etched. × 100. Fig. 6—Specimen 1C, carburized, cooled, reheated, quenched, edge etched. × 100.

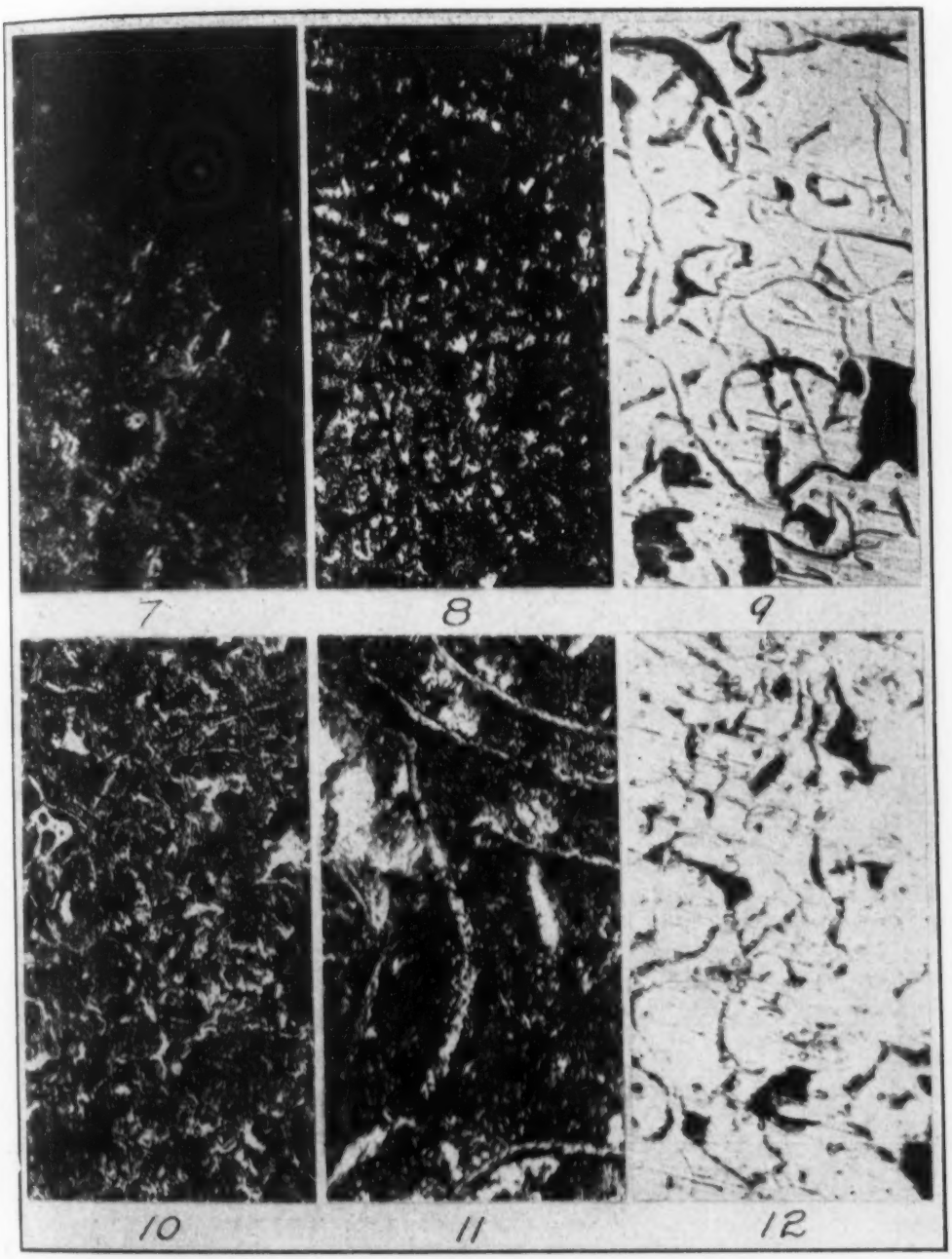

Fig. 7—Specimen 1C, carburized, cooled, reheated, quenched, edge etched. × 400. Fig. 8—Specimen 1C, carburized, cooled, reheated, quenched, center etched. × 100. Fig. 9—Specimen 2A as cast, unetched. × 100. Fig. 10—Specimen 2A as cast, etched. × 100. Fig. 11—Specimen 2A as cast, etched. × 400. Fig. 12—Specimen 2B, carburized, cooled, unetched. × 100.

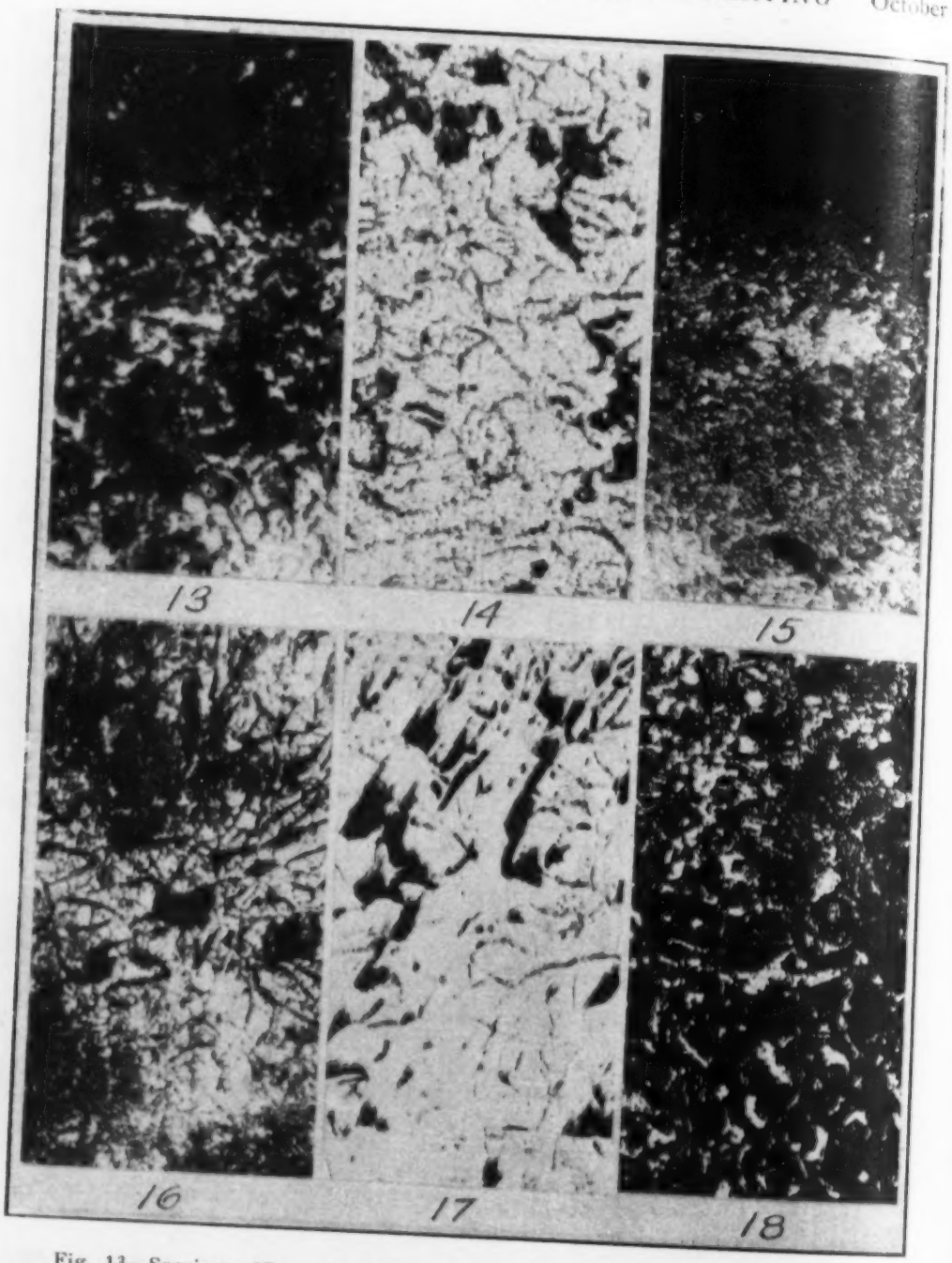

Fig. 13—Specimen 2B, carburized, cooled, edge etched. × 100. Fig. 14—Specimen 2B, carburized, cooled, center etched. × 100. Fig. 15—Specimen 2G, carburized, cooled, reheated, quenched, edge etched. × 100. Fig. 16—Specimen 2G, carburized, cooled, reheated, quenched, center etched. × 100. Fig. 17—Specimen 3E as cast, unetched. × 100. Fig. 18—Specimen 3E as cast, etched. × 100.

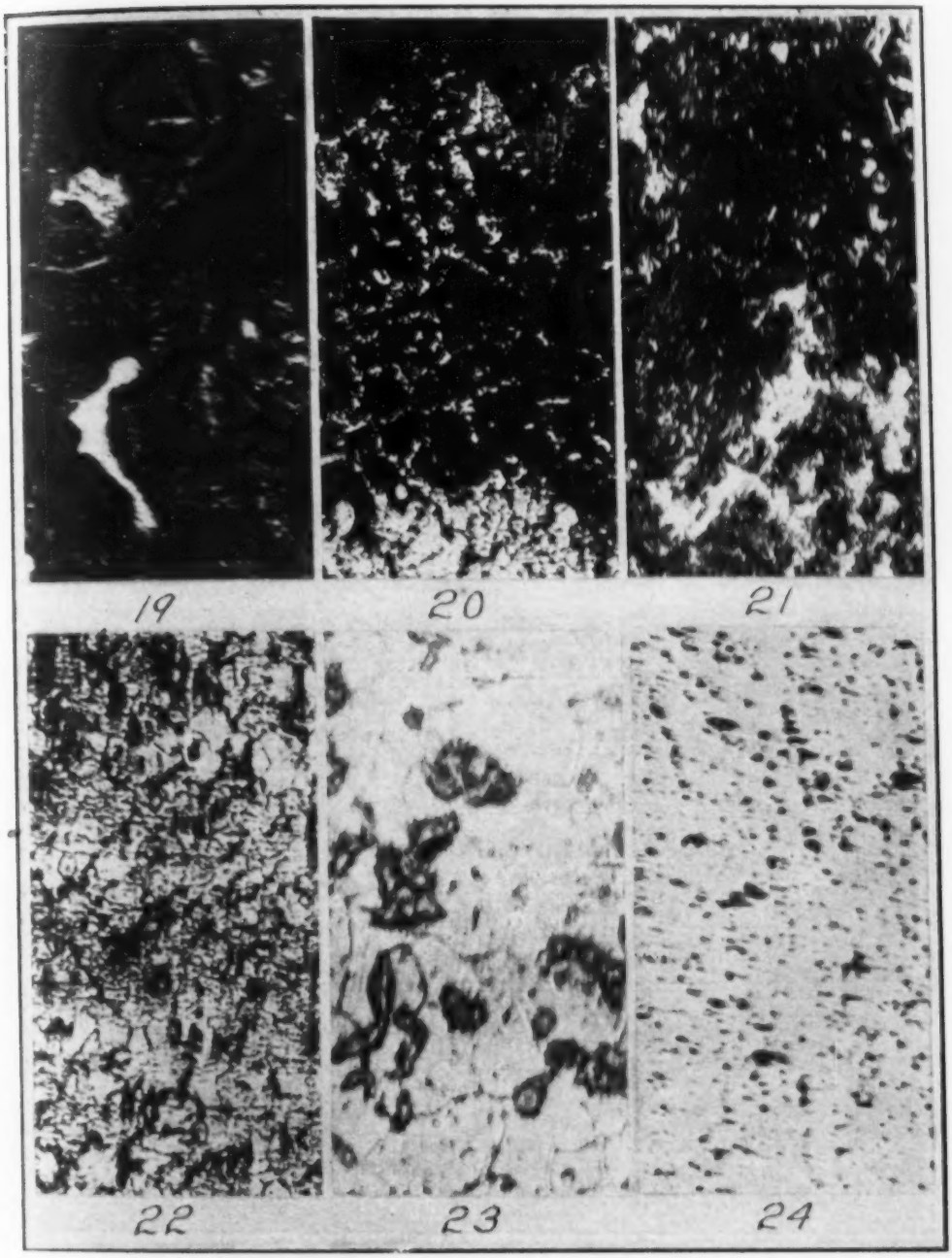

Fig. 19—Specimen 3E as cast, etched. × 400. Fig. 20—Specimen 3D, carburized, cooled, edge etched. × 100. Fig. 21—Specimen 3D, carburized, cooled, near edge etched. × 400. Fig. 22—Specimen 3D, carburized, cooled, center etched. × 100. Fig. 23—Specimen 3D, carburized, cooled, center etched. × 400. Fig. 24—Specimen 3C, carburized, cooled, reheated, quenched, unetched. × 100.

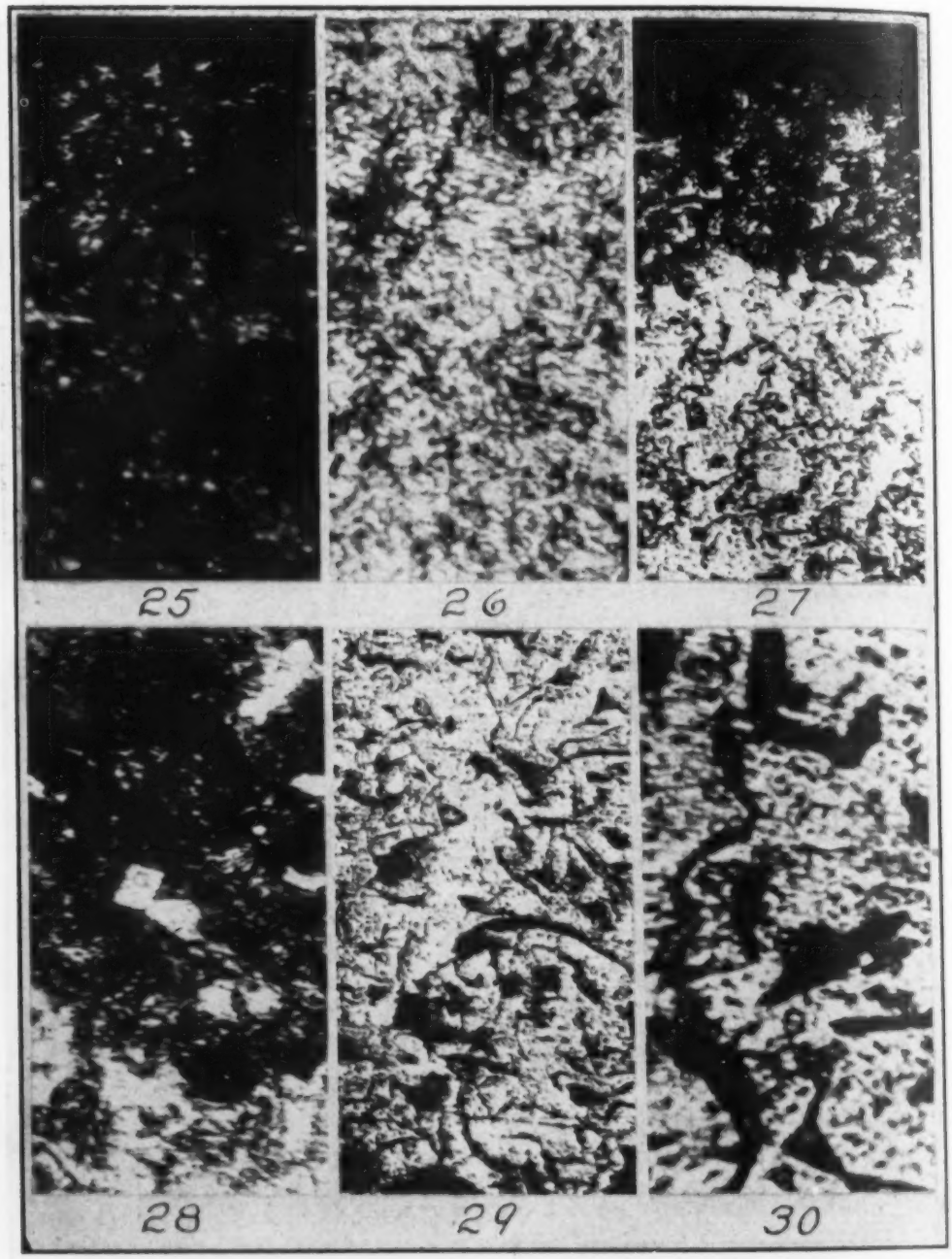

Fig. 25—Specimen 3C, carburized, cooled, reheated, quenched, edge etched. × 400. Fig. 26—Specimen 3C, carburized, cooled, reheated, quenched, center etched. × 350. Fig. 27—Specimen 3H, heated in clay, cooled, edge etched. × 100. Fig. 28—Specimen 3H, heated in clay, cooled, near edge etched. × 400. Fig. 29—Specimen 3H, heated in clay, cooled, center etched. × 100. Fig. 30—Specimen 3H, heated in clay, cooled, center etched. × 100.

broad zone at the edge which is largely pearlite. This corresponds very closely in appearance with the case of a case carburized steel except that there is free graphite present in these cases. Apparently the combined carbon in these zones is at least a little higher than in the original casting. (Note:—3B and part of 3D did not show the pearlitic zone at the edge. This may have been due to the leaky condition of the carburizing container. The quenched specimens of this series hardened properly, indicating that the outer zones must have been largely pearlite). The photomicrographs of the centers of the carburized, slowly cooled samples, show much more free ferrite than in the original casting. Evidently during the long heating the combined carbon in the center, broke down into its constituents, graphite and free ferrite. In the specimens which were reheated and quenched, some of this free ferrite has disappeared. Evidently it has been dissolvd in the formation of the semihardened structure. The photographs of sample 3H are shown in Figs. 27-30. It will be noted that here too there is a pearlitic band at the outside but that it is not as deep as those produced by heating for three hours in a carburizing material, and not nearly as deep as the one produced by 8 hours carburization. It will also be noted that there is a tendency towards decarburization at the extreme edge. The decomposition of the combined carbon in the core is noted as before.

Conclusions

This paper is not complete and exhaustive enough to be the basis for any final conclusions. There are many things yet to be worked out. Future work may alter the opinions which would be drawn from this paper alone. The paper does demonstrate the possibility of greatly improving the quality of gray cast iron. The best samples in this series were hard and at the same time had a toughness almost comparable with that of a case hardened low carbon steel. They were considerably stiffer than malleable castings. It would seem that the production of such a combination of properties from cheap gray cast iron, might have considerable commercial value.

There may be differences of opinion as to exactly what took place, during the "carburizing" heat, as well as the reasons for them. In the first place it seemed quite evident that the combined

carbon in the center decomposed into ferrite and graphite. In other words, the action was the familiar malleablizing annealing, except that the amount of combined carbon in the original casting was lower than customary. This meant that the decomposition or annealing did not require as much time. The carbon, however, which was in the plate form in the original casting was inclined to remain in that condition. This could not be considered an advantage. Fig. 24 shows that sample 3C after heat treating, contained graphite mostly in the globular form. Two other photographs of heat treated samples from bar No. 3 showed the same condition. The writer does not see the explanation.

What happens in the outer zones of these pieces when heated in contact with a carburizing material, may also be open to speculation. At the end of the run it is noted that the outer layer is mostly pearlite. Of course there was considerable pearlite in the casting to begin with. It would be interesting to try the same process on a cast iron containing as little combined carbon as possible. It seems probable that the combined carbon in the outer zone is actually increased by the "carburizing" run. Why should this take place? Does the pressure or quantity of carbon monoxide gas in the carburizing box, produce a different condition of chemical equilibrium with which a higher amount of combined carbon in the outer zone, is in balance? Why should heating favor decomposition of the combined carbon in the center and the formation of the same compound near the surface? Does it not seem reasonable that this may be due to the action of the gases generated by the carburizing material?

Another question which may well be raised, is; what composition of cast iron would be the most suitable. If the silicon is very high and the combined carbon very low, it might be possible that the excess of graphitic carbon might retain the plate form which would mean a weakness. Again if the silicon were very high would it not prevent the formation of pearlite in the outer zone? If the silicon were very low there would be a great deal of combined carbon in the casting to begin with. This might require considerable heating to break down and toughen. Also, if the silicon were low, would it favor the formation of excessive combined carbon in the outer zone and cause brittleness?

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The following bibliography covers the literature on Hardness Testing. The work on this bibliography was carried out at the instigation of Dr. H. L. Whittemore of the U. S. Bureau of Standards and was donated to the National Research Council Committee on Hardness Testing by the American Society of Mechanical Engineers who prepared it in their Library in New York. Additional references were supplied by Dr. P. D. Merica of the International Nickel Company and Dr. H. P. Hollnagel of the General Electric Company.

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Guillery. Testing hardness of metals, 1914. (In Chemical Abstracts, Vol. 8, p. 317. Guillery's Brit. Pat. 16879, 1912). A ball is brought into contact with the metal by a screw which serves as a micrometer screw for measuring the depth of impression.

Hadfield, R. A. The hardening of metals. 1914. (In Transactions Faraday Society, Vol. 10, p. 207-11. Abstracted Journal Iron

and Steel Institute, Vol. 90, p. 368). Discusses progress made in scientific methods for the accurate determination of hardness of metals.

Hanemann, H., and Schulz, E. H. Formanderungen, Spannungen und Gefugeausbildung beim Harten von Stahl. 1914. (In Stahl und Eisen, Vol. 34, p. 399-405, 450-7). Form-changes of steel during hardening and influence of stresses on hardness of carbon steel and special steel containing nickel, chromium.

Hardness testing. 1914. (In Engineering, Vol. 117, p. 281-3. Abstracted Journal Institute of Metals, Vol. 11, I, p. 326). Illustrated description of the Martens hardness tester, methods of testing and of the tabulation of results.

Hardness and warpage of shrapnel case metal. 1914. (In Tests of Metals, p. 36-8).
Data on hardness, after annealing, of the metal, containing 3.5 per cent of nickel.

Heat treatment of nickel-vanadium steel. 1914. (In Tests of Metals, p. 146-52).
Curve, 4, p. 150, shows the Brinell ball hardness number for two specimens of heat treated steel.

Hess, H. Brinell hardness tests. 1914. (In American Machinist, Vol. 41, p. 274. Abstracted Chemical Abstracts, Vol. 9, 1915, p. 586). Suggests to adopt the standard diameter of the ball as 10 mm. (0.4 in.) with a permissible variation of 0.0025 mm. or 0.0001 in., plus or minus and to measure the ball after each impression.

Kelley, E. J. Methods of determining hardness. 1914. (In Mechanical Engineer, Vol. 34, p. 122-4). Iron Trade Review, Vol. 55, p. 117-8, 142b. c. Abstracted Journal Iron and Steel Institute, Vol. 91, p. 597, 1915). Describes and discusses the various methods of hardness determinations and the specific application of the different kinds of tests to ascertain different kinds of hardness.

Kuhnel, R., and Schulz, E. H. Harteprufer, 1914. (In Giesserei Ztg., Vol. 11, p. 1-5, 56-9, 89-93). Analyzes the various apparatus and methods used for determining hardness. Describes and illustrates the apparatus of Martens, Brinell, Shore and their use for various purposes. Recommend the apparatus of Shore and Schneider for use in factories and the apparatus of Martens for metallographic purposes.

Lead advantageous in refining steel. 1914. (In Automobile, Vol. 31, p. 364-5). Lead used in hardening steel.

Local surface-hardening of high tensile steels. 1914. (In Engineering, Vol. 97, p. 212-4. Abstracted Chemical Abstracts, Vol. 8, p. 1257). Illustrated description of Vicker's method of using an equipment for oxyacetylene welding.

Means for ascertaining the hardness of metals or other materials. 1914. (In Journal Society Chemical Ind. Vol. 33, p. 425. Abstract of Rudge-Whitworth's and Heathcote's Eng. Pat. 6622, 1913). Based upon the fact that the friction between the body to be tested and a hard rough surface, such as that of a file, is less for the harder body.

Portevin, M. A. Influence du temps de chauffage avant la trempe sur les resultats de cette operation. 1914. (In Bulletin de la Societe d'Encour. pour l'Ind. Nat., Vol. 122, p. 207-82). Effect of the durability of heating in hardening on the results obtained by this operation. Heating in a salt bath; mechanical tests on various steels; Brinell tests on special carbon steels after various treatments; Brinell and Shore tests on molybdenum steels.

Ricalfi, F. Describes a portable hardness testing machine. Tube with piston and hardened ball with spring to measure pressure. (Metallurgia Italiana, Vol. 6, p. 199-202).

Shore, A. F. What is hardness? 1914. (In Engineering, Vol. 98, p 84-5. Abstracted Journal Iron and Steel Institute, Vol. 90, p. 368). Gives a definition of hardness and the principle of the scleroscope for measuring hardness.

Shore, A. F. Scleroscope, U. S. Pat. 1121050. 1914. (In Official Gazette, Vol. 204, p. 833). Having a specially graduated tube and a very light striker freely movable in the tube and means for controlling the movement of the striker.

Simpson. Hardening the surfaces of iron and steel. 1914. (In Chemical Abstracts, Vol. 8, p. 2336. Abstract of Simpson's German Pat. 270535, 1912). By cementation and introduction of metals by means of the electric current in vacuo.

Skillman, V. Brinell hardness testing of nonferrous alloys. 1914. (In Transactions American Institute of Metals, Vol. 8, p. 151-60). Gives the principle of the Brinell test and the standard methods with table of results of tests made with two different loads. Phosphor bronze, gun bronze, manganese bronze of varying composition have been tested. Table with usual hardness of some common alloys. Brinell and scleroscope readings.

Stanton, T. E. and Batson, R. G. C. Hardness and wear of metals—Brinell and Janiter wear test. (Report of National Physical Laboratory).

Sweet, **E.** Method of hardening iron and steel. U. S. Pat. 1121572. 1914. (In Official Gazette, Vol. 209, p. 1014). By heating to a red heat in a bath of molten KCN with addition of animal charcoal and by quenching in oil after removal from the molten material

Thomas, **J. J.** Hardness tests: relation between Brinell ball test and scleroscope readings. 1914. (In Proceedings American Society for Testing Materials, Vol. 14, II, p. 72-5. Abstracted Mechanical Engineer, Vol. 34, p. 92). Illustrated by means of curves. Tests were carried out on chrome-nickel steel, nickel steel, carbon steel, bronze, cast iron and aluminum. The scleroscope readings vary more with the different metals or even in the same metal than the ball tests.

Vicker. Hardening steel. 1914. (In Chemical Abstracts, Vol. 8, p. 56. Abstracted Vicker's French Pat. 453235, 1913). By means of the flame of an C_2H_2 blast at about 750 degrees Cent.

Wright, **A. P.** Use of chemicals in hardening of metals. 1914. (In Metal Industry, Vol. 12, n. s., p. 384). Short note. Antimony is recommended for hardening metals in general, sulphur for hardening lead and tin.

Wuesler, **G.** Machine for hardening steel. U. S. Pat. 1118723. 1914. (In Official Gazette, Vol. 208, p. 1257). Comprising a tank for the hardening liquid with connections for supplying and controlling an air pressure, a cylinder with a movable head and a support for the metal to be hardened under pressure, means for limiting the movement of the head, and means for collecting the liquid discharged.

1915

Abbott, **R. R.** Relation between maximum strength, Brinell hardness and scleroscope hardness in treated and untreated alloy and plain steels. 1915. (In Proceedings American Society for Testing Materials, Vol. 15, pt. 2, p. 42-61). Results obtained on carbon, nickel, chrome-vanadium, high chrome-nickel, and low chrome-nickel steels are considered.

A. **S. B.** The testing of materials by means of the scleroscope. 1915. (In Automobile Engineering, Vol. 5, p. 223-5. Abstracted Journal Iron and Steel Institute, Vol. 92, p. 307). Deals with the testing of mild Siemens-Martin and Bessemer steel, of tool steel, hign-speed steel, case hardened parts, bronzes, copper, brass, etc.

Brown, S. L. Process of hardening iron, U. S. Pat. 1190568. 1915. (In Official Gazette, Vol. 214, p. 1111). By heating it to a white heat and their immersing it in boiling NaCl for a short time.

Cain, P. H. Factors in the heat treatment of steel. 1915. (In Railway Master Mechanics, Vol. 39, p. 127-9). Contains brief note on hardening and tempering of tool steel.

Chapman, R. W. Demonstration of strain-hardening of steel. 1915. (In Nature, Vol. 94, p. 589. Abstracted Journal Iron and Steel Institute, Vol. 92, p. 306). A photograph shows the changes in the side of a steel bar due to strain.

Comparison of hardness testing apparatus. 1915. (In Machinery, Vol. 21, p. 364). The Shore scleroscope test is compared with the Brinell hardness test.

Effect of duration of drawing on physical properties of hardened nickel steel. 1915. (In Tests of Metals, p. 191-203). Data are given on Brinell hardness after drawing and quenching of hot rolled nickel steel containing 3.19 per cent of nickel. It is shown that Brinell hardness of water cooled steel is higher than when air cooled.

Effect of carbon on the physical properties of heat-treated carbon steel. 1915. (In Tests of Metals, p. 204-23). Composition of the steel is given and results of Brinell hardness tests are summarized in the accompanying tables.

Edwards, C. A. and Kikkawa, H. Effect of chromium and tungsten upon the hardening and tempering of high-speed tool steel. 1915. (In Journal Iron and Steel Institute, Vol. 92, p. 6-45. Conclusions of this paper in Engineering, Vol. 120, p. 313-4). Results of hardness tests are tabulated. It is stated that the greatest hardness is associated with the high volume.

Evans, G. S. Testing the hardness of iron castings. 1915. (In Iron Age, Vol. 96, p. 8-10. Abstracted Journal Iron and Steel Institute, Vol. 93, p. 372). Two types of testing attachments are shown: One for use with a Riehle universal machine and the other with a Tinius Olsen transverse testing machine. Method of determining hardness by the Ball impression test is described.

Examination of aluminum bronze. 1915. (In Tests of Metals, p. 244). The Brinell hardness of commercial aluminum bronze containing 89.11 per cent of copper, 10.0 per cent aluminum, and 0.94 per cent iron was found equal to 144.

Friedmann, H. Tool for hardness tests. 1915. (In Iron Trade Review, Vol. 57, p. 899). Illustrated description of a small drilling machine.

Hanley, W. Treatment of special steels. 1915. (In Practical Engineering, Vol. 52, p. 136-7). Contains brief note on hardness of nickel steels and table giving Brinell hardness for steel containing 3 and 5 per cent of nickel.

Haerten Kleiner Stahlstuecke. 1915. (In Elektrochemische Ztschr., Vol. 22, p. 66-7. Abstracted Chemical Abstracts, Vol. 9, p. 2374). Recommends a water bath covered with oil for hardening of small steel pieces.

Howe, H. M. Hardening with and without Martensitization. 1915. (In Transactions Faraday Society, Vol. 10, p. 265-70. Engineering, Vol. 99, p. 87-9. Abstracted Journal Iron and Steel Institute, Vol. 91, p. 584). Discusses the amorphous theory of the hardening of steel by rapid cooling and the influence of the rate of cooling on the hardness of Hadfield's manganese steel.

Hydraulic hardness testing machine. 1915. (In Chemical and Metallurgical Engineering, Vol. 13, p. 646. Abstracted Chemical Abstracts, Vol. 9, p. 3208). Working on the Brinell principle of making indentations in the metal and measuring the width of the same by a special microscope.

McFarland, D. F. and Harder, O. E. Alloys of chromium, copper and nickel. 1915. (In Transactions American Institute Metals, Vol. 9, p. 119-44). Contains a note on hardness tests, with hardness numbers increasing with increase of chromium and table giving Brinell hardness numbers for a series of alloys.

McLarty. Iron, copper, etc. 1915. (In Chemical Abstracts, Vol. 9, p. 1297. Abstract of McLarty's Brit. Pat. 27141, 1913). Hardening, preserving from oxidation by subjecting them to the action of gases and vapors produced by heating a mixture of H_2O, hydrocarbons, carbohydrates, etc. Free oxygen may be withdrawn before treatment.

McWilliam, A. and Barners, E. J. Brinell hardness and tenacity factors of a series of heat-treated special steels. 1915. (In Journal Iron and Steel Institute, Vol. 91, p. 125-39). Tests were carried out with chromium-steels, nickel steels, vanadium steels. Discussion.

Mathews, J. A., and Stagg, H. J. Factors in hardening tool steel. 1915. (In Journal American Society Mechanical Engineers, Vol. 37, p. 141-7. Abstracted Journal Iron and Steel Institute, Vol. 91, p. 582-3). Considers time of heating, speed of quenching, hardness as affected by mass, time and degree of drawing, temper, furnaces and methods of heating. Results of tests are given as curves.

Meneghini, D. Hardness tests of copper-zinc alloys. 1915. (In Iron Trade Review, Vol. 57, p. 1240). Gives the arrangement and illustration of an apparatus operating under a slight pressure exercised by a ball of small diameter. Tabulated results of hardness tests on copper zinc alloys.

Olsen, T. Machine for testing hardness. U. S. Pat. 1141881. 1915. (In Official Gazette, Vol. 215, p. 277). Including means for applying a load to a piece under test.

Portevin, A. L'essai a la bille sur les metaux et alliages bruts de coulee. 1915. (In Revue de Metallurgie, Memoirs, Vol. 12, p. 95-100. Abstracted Journal Iron and Steel Institute, Vol. 92, p. 306-7). Brinell hardness test on metals and alloys in rough-cast condition. Causes of irregular results often met with. Results of Ball tests on bronze, brass.

Portevin, A. Shape of impression by falling ball. (Comptes Rendus, Vol. 160, p. 344-6).

Schulz, E. H. Die Volumen und Formanderungen des Stahles beim Harten. 1915. (In Ztschr. Ver. d. Ingen., Vol. 59, p. 66-71, 112-6. Abstracted Iron Age, Vol. 95, p. 1399-1402). On the changes in volume and shape taking place in steel with hardening. Analysis of steels used in investigation and hardness tests.

Shepard & Porter. Hardness tests of cold-rolled steel. 1915. (In American Machinist, Vol. 42, p. 277-8. Abstracted Journal Iron and Steel Institute, Vol. 91, p. 597, 1915). Determines the relation between the ultimate tensile strength of cold-rolled steel and the hardness number as found by the Brinell and scleroscope tests. Author believes that the Brinell hardness test gives more valuable results in determining the ultimate tensile strength than the scleroscope test.

Skillmann, V. Brinell hardness-testing of nonferrous alloys. 1915. (In Foundry, Vol. 43, p. 111-2). Describes method of testing hardness by scratching, the Brinell test. Tables show hardness of various phosphor bronze alloys of gun bronze, manganese bronze and of some common alloys as white brass, babbitt, etc.

Turpin. Essais de durete executes avec un appareil a main. 1915. (In Revue de Metallurgie, Memoirs, Vol. 12, p. 104-12. Abstracted Iron Age, Vol. 96, p. 923). A simple hand device adapted to determining hardness with a satisfactory degree of accuracy. Method of carrying out tests and of calculating the results is given.

Uber den Harteversuch an Automobil Konstruktion Stahl. 1915. (In Autom.-Rundschau, Vol. 14, p. 119-20). Hardening of steel by heat treatment.

White. Hardening copper, 1915. (In Chemical Abstracts, Vol. 9, p. 2220. Abstract of White's French Pat. 467583, 1914.) By heating it to redness or whiteness, plunging it for a short time into a hardening bath of milk of lime with additions of vegetable extracts, and then hammering it.

1916

Abbott, **R. R.** Heat treatment of automobile steels. 1916. (In Bulletin Society of Automotive Engineers, Vol. 11, p. 32-44). Paper and discussion containing a brief note on hardening near critical points.

Arnold, **J. O.** Note on the relations between the cutting efficiencies of tool steel and their Brinell or scleroscope hardness. 1916. (In Journal Iron and Steel Institute, Vol. 93, p. 102-13. Abstracted Iron Age, Vol. 97, p. 1207). States that the Brinell hardness of a properly hardened tool is a negligible factor of efficiency.

Automatic steel hardening and tempering machine. 1916. (In Machinery, Vol. 22, p. 998-9). Designed to provide for automatically and uniformly hardening and tempering steel product, especially small thin pieces.

Bray, **N. H.** Process of Carburizing and hardening metals. U. S. Pat. 1207848. 1916. (In Official Gazette, Vol. 233, p. 412). By heating the metal to a highly absorbent degree with an acetylene flame.

Brinell hardness perpendicular to and in the direction of forging or rolling. 1916. (In Tests of Metals, p. 123-7). Cold rolled, machined, forged steel samples were tested.

Brinell meter for hardness tests. 1916. (In Machinery, Vol. 22, p. 818). Description of the Brinell meter of the Standard Roller Bearing Co.

A convenient hardness measuring instrument. 1916. (In Iron Age, Vol. 97, p. 1195). Known as the "Brinell meter" designed to give accurate results independent of the dimensions, shape and location of the material tested.

Friedmann, H. Testing nonferrous metals for hardness 1916. (In Machinery, Vol. 22, p. 1026-8). Applications of the Brinell method in regulating methods of manufacture. Tables with hardness tests of aluminum sheets, copper sheets, etc.

Fry, L. H. What is heat treated steel? 1916. (In Railway Mechanical Engineer, Vol. 90, p. 335-7). Deals briefly with hardness produced by heat treatment.

Hadfield, R. A. Memorandum on hardness. 1916. (In Proceedings Institute Mechanical Engineers, Oct.-Dec. p. 707-11). Criticizes the methods of measuring hardness.

Hardness. 1916. (In Tests of Metals, p. 31-2). Description of hardness tests carried out with 2 brass bars of different composition as received, and after compression, annealing and cold work.

Hardening high-speed steel. 1916. (In Iron Trade Review, Vol. 59, p. 270). Directions of the Vanadium-Alloys Steel Co., distributed for hardening high-speed steel.

Hardness tests for metals. 1916. (In Times Engineering Supplement, Vol. 12, no. 504, p. 164). Description of the Brinell test, the Shore scleroscope, the limitations of all hardness tests and applications of hardness tests to plain carbon steel, carbon, tungsten, chrome, vanadium steel.

Howe, H. M. and Levy, A. G. Notes on the hardening and tempering of eutectoid carbon steel and on the Shore test. 1916. (In Proceedings of the 19th meeting of the American Society Testing Materials, Vol. 16, pt. 2, p. 5-52. Abstracted Iron Trade Review, Vol. 59, p. 372). Showing the influence of the quenching temperature and of the temperature and time of tempering on the hardness and on the microstructure of quenched (hardened) steel containing 0.92 per cent carbon. It records, further certain preliminary studies of the Shore scleroscope test. Results of numerous hardness tests are tabulated.

Improvements in the technique of Brinell hardness determinations. 1916. (In Chemical and Metallurgical Engineering, Vol. 14, p. 611-2. Abstracted Chemical Abstracts, Vol. 10, p. 2342-3). The Brinell method is made independent of the dimensions, shape and location of the metal mass. The "sampling error" in cutting specimens for tests is eliminated.

Latest improvements in Brinell hardness testing machines. 1916. (In Chemical and Metallurgical Engineering, Vol. 14, p. 58-60). A direct-reading depth gauge is carried by the Scimatco-Brinell machine and gives correct indications to 1/100 of a millimeter independent of the shape of the test piece.

McFarland, D. F., and Harder, O. E. Preliminary study of the alloys of chromium, copper and nickel. 1916. (In University Illinois Bulletin No. 93, 66 pp. Engineering Experimental Station). P. 16-8: Brinell hardness number tests were made on numerous alloys of varying composition and on some pure metals and results are tabulated.

Moore, R. W. E., and Edgecomb, H. R. Hardness testing apparatus and method. U. S. Pat. 1192670. 1916. (In Official Gazette, Vol. 228, p. 1357). Method of testing metals by means of a machine forming surface indentations.

Report of the Hardness Tests Research committee. 1916. (In Proceedings Institute of Mechanical Engineers, Oct.-Dec., p. 677-701. Engineering, Vol. 102, p. 556-8, 597-9). Detailed description of experiments made at the National Physical laboratory, on hardness with analysis of various methods for hardness determination. Results of tests on hardness of different steels and bronze. Relation between hardness and resistance to wear.

Portable hydraulic hardness testing machine. 1916. (In Chemical and Metallurgical Engineering, Vol. 14, p. 612). Illustrated note.

Richardson, C. E. Artificial gas-fired furnace installation. 1916. (In Journal Industrial and Engineering Chemistry, Vol. 8, p. 911-4. Abstracted Journal Iron and Steel Institute, Vol. 95, p. 378). Illustrated description of hardening furnaces.

Ricolfi, F. 1916. (In Metallurgia Italiana, Vol. 8, p. 690-9. Abstracted Journal Iron and Steel Institute, Vol. 95, p. 400). Discusses the application of the Brinell method of hardness testing for controlling the manufacture and treatment of projectiles.

Stanton, T. E. and Batson, R. G. Report of committee on hardness tests. Quite comprehensive—gives description of different methods. (Proceedings Institute Mechanical Engineers, Oct.-Dec., pp. 677-723).

Thomas, W. N. A few experiments on the hardness testing of mild steel. 1916. (In Journal Iron and Steel Institute, Vol. 93, p. 255-69). Carried out in order to show the effect of time upon the determination of Brinell's hardness number, the relation between the applied pressure and the area and the diameter of the impression, the influence upon the "hardness factor" of the work done upon the specimen during application of the load and to consider the effect of the thickness of the specimen.

Turner, T. Hardening and annealing of metals. 1916. (In Journal Chemical Metallurgical and Mining Society So. Africa, Vol. 17, p. 61-6). Deals briefly with cold working of metals and its influence on hardness.

Unwin, W. C. Memorandum on tests of hardness and resistance to wear. 1916. (In Institute Mechanical Engineers. Oct.-Dec., p. 701-5). Describes briefly Turner scratch test, the indentation methods, the Brinell hardness test, the Shore scleroscope, and the relation between hardness and resistance to abrasion or wear.

Van Deventer, J. H. Hardening and softening steels. 1916. (In Machinery World, Vol. 60, p. 15-6). Describes briefly methods of heating for hardening and tempering.

Vickers & Smith. Apparatus for determining the hardness of a body. 1916. (In Journal Society Chemical Industry, Vol. 35, p. 895. Abstracted Vickers & Smith's Eng. Pat. 11936, 1915). By causing a hard steel ball by a single blow of a hammer to make impressions simultaneously on a bar of standard hardness and on the surface to be tested.

1917

Anderson, R. J. Notes on the heat treatment of high-speed steel tools. 1917. (In Bulletin Transactions American Institute Mining Engineers, Mar., p. 408-15). Discusses the paper of Bellis and Hardy on heat treatment of high-speed steel and suggests to harden by heating under close pyrometric control.

Bellis, A. E., and Hardy, T. W. Notes on the heat-treatment of high-speed steel tools. 1917. (In Transactions American Institute Mining Engineers, Bulletin Jan., p.. 61-8). Experiments on hardening of high-speed steel in which metallographic means were used to determine the correct hardening temperatures. Numerous micrographs of steel hardened at different temperatures.

Brayshaw & Yates. Hardening and tempering furnaces. 1917. (In Mechanical Engineer, London, Vol. 39, p. 108. + Abstracted Jour-

nal Iron and Steel Institute, Vol. 95, p. 378). Illustrated description of a furnace for hardening and tempering steel.

Burton, W. L. The hardening of steel. 1917. (In Mining and Engineering Review, Vol. 9, p. 292-5). Deals with the heat treatment and its influence on the composition and hardness of steel. Gives results of hardening trials of steel bars.

Chubb, T. W. Recent British hardness tests of engineering materials. 1917. (In American Machinist, Vol. 46, p. 138). It was concluded that "the Brinell hardness numbers of a miscellaneous selection of steel are not a safe guide in predicting their relative resistance to wear."

Constitution et durete des alliages cuivre-aluminum riches en cuivre. 1918. (In Metallurgie, Vol. 50, No. 45, p. 1631-3). Effect of tempering temperature on hardness of alloys containing 9-16 per cent of aluminum. Results of Brinell and scleroscope hardness tests are tabulated.

Davis, E. F. Lead hardening. 1917. (In Gas Age, Vol. 40, p. 307-10). On the use of a lead bath for steel hardening. The furnaces used in lead hardening.

Davis. Testing of sheet brass. 1917. (In Proceedings American Society for Testing Materials, Vol. 17, 2, p. 164-98). Brinell and scleroscope tests were made and results tabulated. Brinell hardness tests of annealed and hard rolled metal do not vary appreciably with the thickness of the metal. Scleroscope and Brinell tests are found to be unsatisfactory on metals below a certain limit of thickness.

Ehlers, W. A. Heat treatment of metals. 1917. (In Industrial Management, Vol. 53, p. 17-28). Describes the process of hardening, temperatures to be maintained and the use of salt solutions in hardening. Describes and illustrate a heating machine for continuous hardening and annealing with automatic heat controller and regulator.

Electrical method of hardening steel. 1917. (In Engineering, Vol. 124, p. 82-3). Description of the Wild-Barfield patented process.

Grenet, L. The penetration of the hardening effect in chromium and copper steels. 1917. (In Journal Iron & Steel Institute, Vol. 95, p. 107-17). Experiments have been made on crucible steels from Firminy. Results are tabulated.

Guillery. Hardness tests. 1917. (In Comptes Rend, Vol. 165, p. 468-71. + Abstracted Chemical Abstracts, Vol. 12, p. 266. Journal

Iron and Steel Institute, Vol. 97, p. 537. Journal American Society Mechanical Engineers, Vol. 39, p. 1035-6). Indicates a source of error in making rapid Brinell tests and method by which the error can be eliminated. Gives the mechanical arrangement used in carrying out tests and data of tests on various materials as mild steel, medium steel and nickel-chrome steel.

Hampson, D. A. How to avoid cracks in hardening. 1917. (In American Machinist, Vol. 47, p. 280). Suggests to use one brand of steel to avoid losses in hardening, to heat slowly, etc.

Hardness testing machine. 1917. (In Machinery, Vol. 24, p. 177). The "Scimatco" Brinell hardness testing machine is provided with a hydraulic press and a standard hardened steel ball.

Hatfield, W. H. Steels used in airplane work. 1917. (In Automotive Industry, Vol. 37, p. 507-9). Heat treatment and their effects on hardness of various steels, case-hardening, air-hardening.

Knight, W. On testing materials. 1917. (In Machinery, Vol. 24, p. 201-3). Notes on the interpretation of results obtained from various tests. Discusses the Brinell hardness test, the scleroscope method.

Lake, E. F. Alloy or carbon steels versus carburized. 1917. (In Mechanical World, Vol. 62, p. 3-4, 18). Briefly deals with hardness of carburized steel.

Ludwik, P. The hardness of alloys. 1917. (In Ztschr. Ver. deut. Ing., p. 547-54. Engineering, p. 444-5, Vol. 104. Abstracted Journal Society Chemical Industry, Vol. 36, p. 1180, Journal Iron and Steel Institute, Vol 97, 1918, p. 537). Varying quantities of different metals were added to copper, tin, lead, zinc, and aluminum, and the hardness of the resulting alloys was ascertained by the Brinell test.

New hardness measuring instrument. 1917. (In Iron Age, Vol. 100, p. 1119. Abstracted Chemical Abstracts, Vol. 12, p. 243). Illustrated description of an apparatus based on the Brinell principle and having a steel ball, which is pressed into the specimen by a hydraulic piston.

Nouvel appareil pour l'essai de durete des metaux a la bille de Brinell. 1917. (In Genie Civil, Vol. 71, p. 265-6). New apparatus for testing hardness by means of the Brinell method. Length of time required to carry out the test is reduced.

Parker, S. W. Mayari and nickel steels compared. 1917. (In Iron Age, Vol. 99, p. 1380-1). Description of the heat treatment; table

giving results of hardness tests of Mayari and nickel steel quenched in water from 800 degrees Cent. and drawn at various temperatures. The Mayari steel drawn at the same temperature has considerably greater hardness than the nickel steel.

Parker, S. W. Properties and structure of nickel steel. 1917. (In Iron Age, Vol. 100, p. 67-9). Shows the influence of annealing at between 125-1450 on nickel steel of 0.22 and 0.41 per cent of carbon.

The Pellin hardness-testing apparatus, a French device. 1917. (In Iron Age, Vol. 99, p. 1247). It is based upon the Brinell dynamic method and has been designed for hardness testing of different metals.

Pierce, E. H. Hardness of hard drawn copper. 1917. (In Proceedings American Society Testing Materials, Vol. 17, 2, p. 114-21). Brinell hardness tests were made both on the surface and at various points in the cross-section. It is concluded that hard-drawn copper wire is equally affected throughout its mass and that the conception of a hard, exterior "skin" is erroneous.

Pyromagnetic indicator. 1917. (In American Machinist, Vol. 47, p. 83). For indicating the critical point on steel parts being heated for hardening.

The quality of hardness. 1917. (In Engineering, Vol. 124, p. 295-6). Editorial on Professor Turner's paper on "Hardness and Hardening."

Robin, M. F. Mesure de la durete par penetration d'une molette. 1917. (In Soc. d'Encourag. pour l'Ind. Nationale, Bull. 127, p. 233-9. Abstracted Journal Iron and Steel Institute, Vol. 97, 1918, p. 536-7). Results of an investigation on hardness measurements by penetration of a circular knife-edge cutter. For measuring the hardness of steel the method is thought to give more exact results than the ball pressure test.

Thompson, J. Hardening high-speed steel. 1917. (In American Machinist, Vol. 46, p. 344). Short note on temperature to be maintained in hardening process.

Turner, T. Hardness and hardening. 1917. (In Journal Institute of Metals, Vol. 18, 2, p. 87-99. Engineering, Vol. 124, p. 254-6). Definition and measurement of hardness. Hardening of pure metals by alloying, cold work and by chilling. Hardness of copper, zinc alloys, etc.

Uranium steel. 1917. (In Tests of Metals, p. 104-5). Brinell hardness of three indifferent makes of uranium steel.

Waldo, L. Apparatus for testing the hardness of metals. U. S. Pat. 1228503. 1917. (In Official Gazette, Vol. 239, p. 44. Abstracted Chemical Abstracts, Vol. 11, p. 2188). A plummet with a conical impression point is allowed to fall upon the material to be tested to determine its hardness.

1918

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Appliances for ascertaining the hardness of metals and other solid materials. (In Journal Society Chemical Industry, Vol. 36, p. 980. Abstract of Eng. Pat. 107685, 1916). By the depth of indentation in the material caused by the predetermined pressure of a hardened ball.

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STATIC AND DYNAMIC TESTS FOR STEEL

By J. M. Lessells

Abstract

The paper deals with certain static and dynamic forms of testing, the tensile test being taken as representative of the former, and the repeated shock and fatigue as representative of the latter.

Certain types of shock and fatigue testing machines are described in detail together with the experimental results obtained from such machines.

The tabulated data shows that the results obtained from the repeated shock tests have a real meaning and are closely related to those obtained from the long-time fatigue tests. Since it has frequently been asserted that there is no such relation between repeated shock and fatigue, these results are of the first importance. On this basis the repeated shock test becomes a short time fatigue test.

Another short time test is discussed in detail in which the endurance limit under fatigue is determined by measuring the deflection of a single test piece while running under a varying load. In general the paper asserts the importance of dynamic testing, cautions the use of such without proper knowledge, and establishes a relation between different forms.

INTRODUCTION

THIS paper is presented with the view of discussing some of the characteristics of static and dynamic forms of testing. The tensile test has been taken as representative of the static

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A paper presented before the Pittsburgh chapter of the Society, June 5, 1923. The author, J. M. Lessels, is engineer in charge of mechanics in the Research laboratory of the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

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forms and the repeated shock and fatigue as representative of the dynamic forms. A relation between these two latter tests is discussed in detail.

Static Testing

Tensile

The tensile test being the chief static test is first considered, this test of course, due to the speeds adopted for commercial

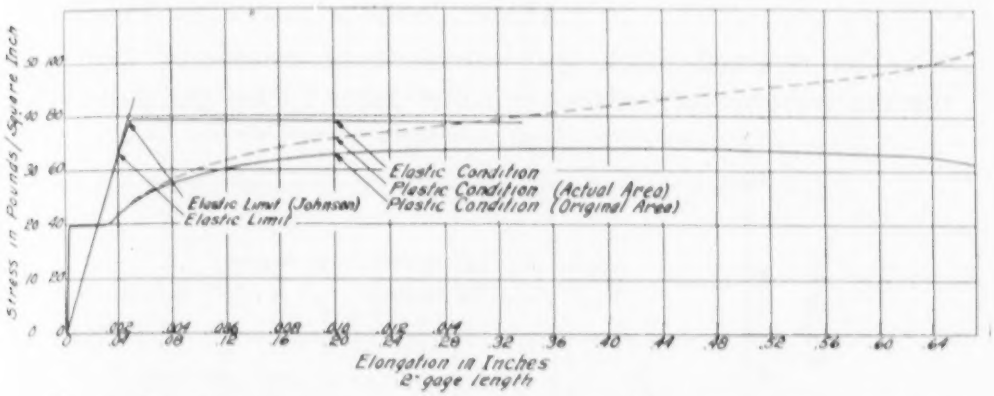

Fig. 1—Tensile Test Diagram for an 0.37 Per Cent Carbon Steel, Annealed. Elastic Limit, 33,000 lbs. per sq. in.; Yield Point, 39,600 lbs. per sq. in.; Maximum Stress (original area), 68,825 lbs. per sq. in.; Maximum Stress (actual area), 117,500 lbs. per sq. in.; Elongation in 2 Inches, 35.4 per cent; Reduction of Area, 50.6 per cent; Modulus of Elasticity, 30.8×10^6; Proof Resilience, 8.82 inch pounds.

testing might scarcely be classified as static, but on the basis that the test piece is stationary it is so considered in this paper.

In a tensile test, there are two values around which much discussion as to the actual meaning of the values, has taken place. Reference is made to the elastic limit and yield point. This contention is all unnecessary since there is no question that we can all agree on the interpretation of such, if we desire to do so. The elastic limit can be taken as that stress at which strain ceases to be proportional to applied load, and yield point as that stress at which an extension of 0.01 inches on a standard test bar has occurred. These values would only be suitable for low and medium carbon steels, but there is no reason at all why an interpretation of such cannot be worked out on this basis which eliminates all such expressions as "drop of the beam," etc. In this manner the yield point would be tied up completely with elastic limit, which is, as it should be.

In Figs. 1 and 2 are shown characteristic tensile test diagrams

on which these two values are recorded on the basis of the previous interpretation. With this brief discussion of the apparent difficulties of the tensile test interpretation, the more complicated forms of testing can now be considered.

Dynamic Testing

There are two forms of dynamic tests; namely the shock test and the fatigue test.

Shock Tests

The repeated shock test will alone be considered here since the other forms of tests were fully discussed by the writer in a

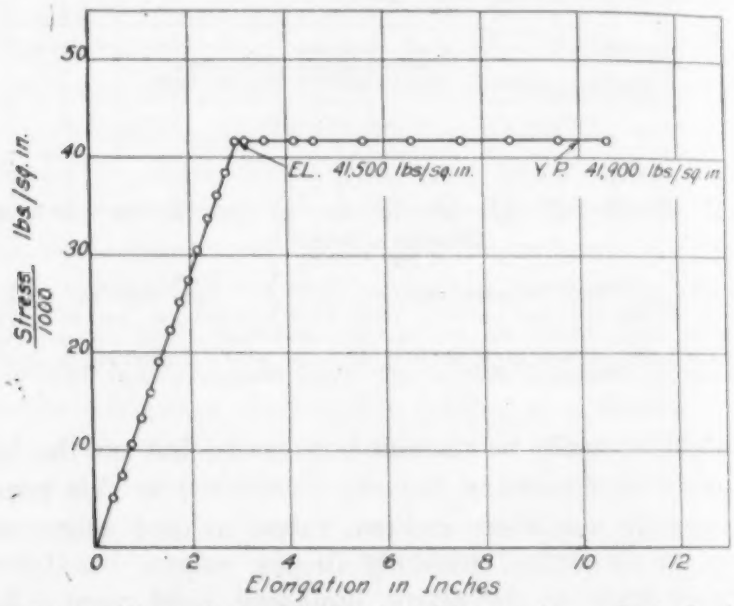

Fig. 2—Elastic Phase of the Tensile Test Diagram for a Steel Casting of 0.33 Per Cent Carbon, Normalized.

paper published in the May, 1922, issue of Transactions. The type of machine used is shown in diagrammatic form in Fig. 3, and is called the Stanton type.

In this machine, the test piece being notched, is struck a blow over the notch alternately 180 degrees apart, the height of drop and the number of blows to fracture being recorded. Tests conducted with such a machine for a single height of drop are of little or no value and the results of such might conceivably be very misleading. Due to the possibility of being able to change the height of the drop a series of results can be obtained, commencing with a 2-inch drop and noting the number of blows to

fracture, then reducing the height of drop on each consecutive test piece until a drop of 0.3-inch has been reached. These results are then plotted so that height of the drop is the ordinate and the number of blows to fracture the abscissa. The type of curve

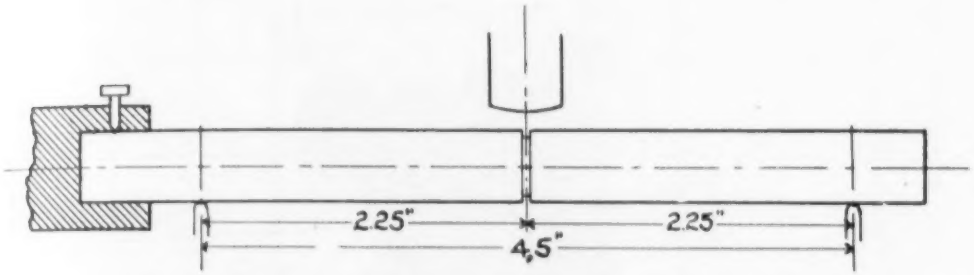

Fig. 3—Diagram of the Stanton Repeated Impact Testing Machine.

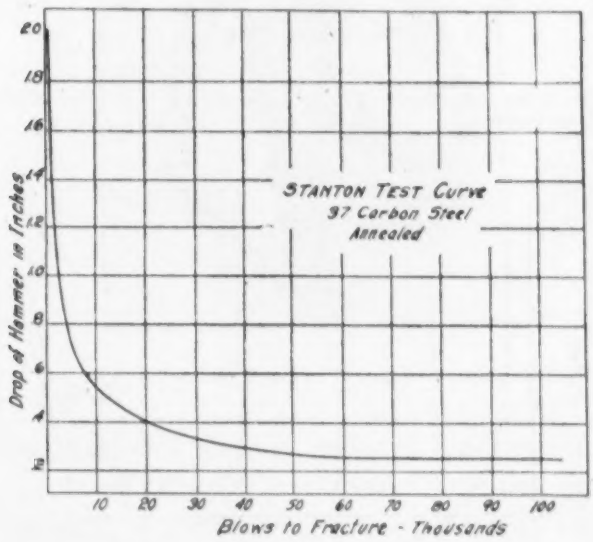

Fig. 4—Repeated Shock Test Curve for a 0.37 Per Cent Carbon Steel, Annealed.

obtained is shown in Figs. 4, 5 and 6. It will be noted that all of these curves are characteristic, just as a tensile test diagram is characteristic.

Fatigue Tests

Fatigue testing machines are of various forms, but only two will be discussed here; namely, the beam type and the cantilever type.

In the beam type, the test piece is freely supported at the

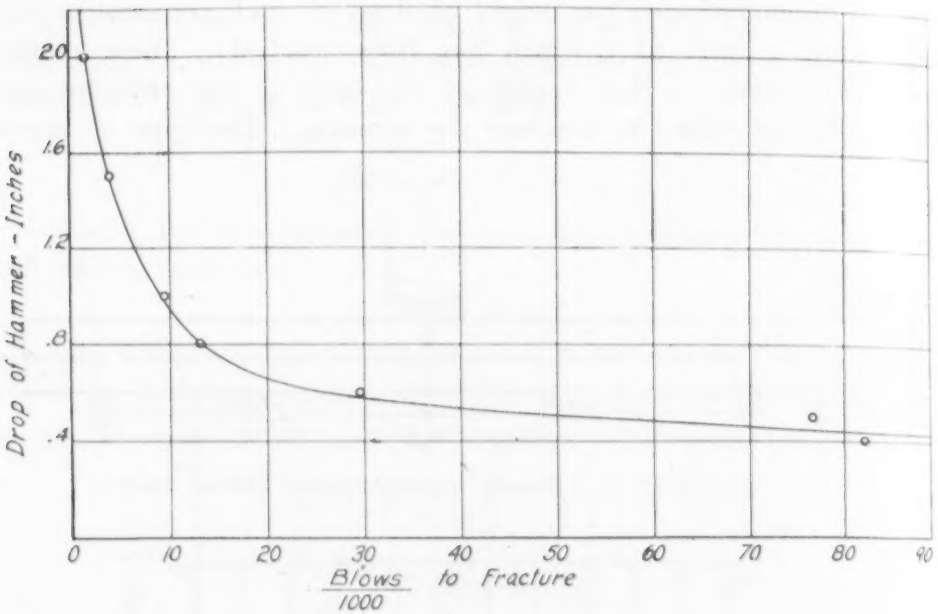

Fig. 5—Repeated Shock Test Curve for a 0.37 Per Cent Carbon Steel Heat-Treated.

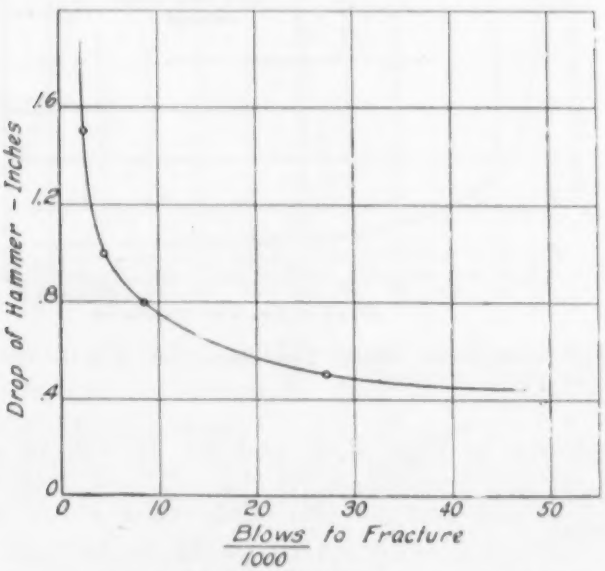

Fig. 6—Repeated Shock Test Curve for a 0.33 Carbon Steel Casting, Normalized.

ends on two ball bearings and loaded through two others, each 1½ inches from the center of the test piece. In the cantilever type the test piece is gripped at one end and is loaded at the other

through a ball bearing. Both types of machines are shown in Figs. 7 and 8. Tests are made on these machines by taking a series of test pieces and commencing with a stress approximately one-half the ultimate stress in tension, and the piece is run to destruction. The number of stress cycles to fracture the specimen, is

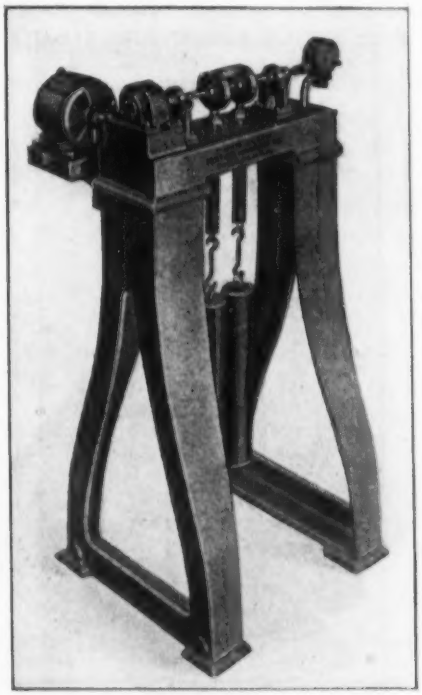

Fig. 7—Beam Type of Fatigue Testing Machine.

recorded. The stress is slightly reduced on successive test pieces until a total cycle of 20×10^6 is obtained without fracture. From the results obtained, a curve having the stress as the ordinate and the cycles of stress as the abscissa, is obtained. Such curves are shown in Figs. 9 and 10.

It will be noted that these curves are of the same general characteristic as those obtained from repeated shock tests. On the assumption that these endurance curves are asymptotic to the horizontal axis the endurance limit is taken as that stress just immediately below, that withstood for 20×10^6 cycles without failure.

Relation Between Endurance and Repeated Shock

As previously stated the curves for endurance and repeated

shock show the same characteristics in that, after certain points, small decrements of stress in the case of fatigue tests, and of height of drop in the case of repeated shock tests, give large increments in the life of the specimen, and that neither break. Since these are similar, the vertical height of the repeated shock curve to-

Fig. 8—Cantilever Type of Fatigue Testing Machine.

wards the right hand should be indicative of the endurance value obtained by the longer methods. To show this, a comparison of such values is given in Table 1.

In this table three steels are considered, a rolled medium carbon steel, a carbon-vanadium steel casting, and a carbon steel casting. Taking the values of the endurance limits (carbon steel as rolled) as unity, and the value from the shock resistance curve at 60,000 blows also as unity, the corresponding relative values for the annealed and normalized states are shown to be 1.01 and 1.06 for the long fatigue tests, and 1.04 and 1.08 for the shock tests. This is also repeated for the steel castings, making the cast condition the basis of comparison. It will be noted that there

is a striking similarity between the two sets of results, showing undoubtedly, that there exists a relation between fatigue and repeated shock, if the results are properly interpreted.

Short Method of Determining Endurance Limit

From what has been previously said, it will be appreciated that the determination of endurance limits is a long process, since

Table I
Relative Endurance Values from Shock and Fatigue Tests

Material	State	Fatigue Tests	Shock Tests
0.37 Carbon Steel	As rolled	1.00	1.00
0.37 Carbon Steel	As annealed	1.01	1.04
0.37 Carbon Steel	As normalized	1.06	1.08
0.3 Car.—0.18 Van. Steel	As cast	1.00	1.00
0.3 Car.—0.18 Van. Steel	As annealed	1.05	1.17
0.3 Car.—0.18 Van. Steel	As normalized	1 07	1.17
0.23 Carbon Steel	As cast	1.00	1.00
0.23 Carbon Steel	As annealed	1.10	1.16

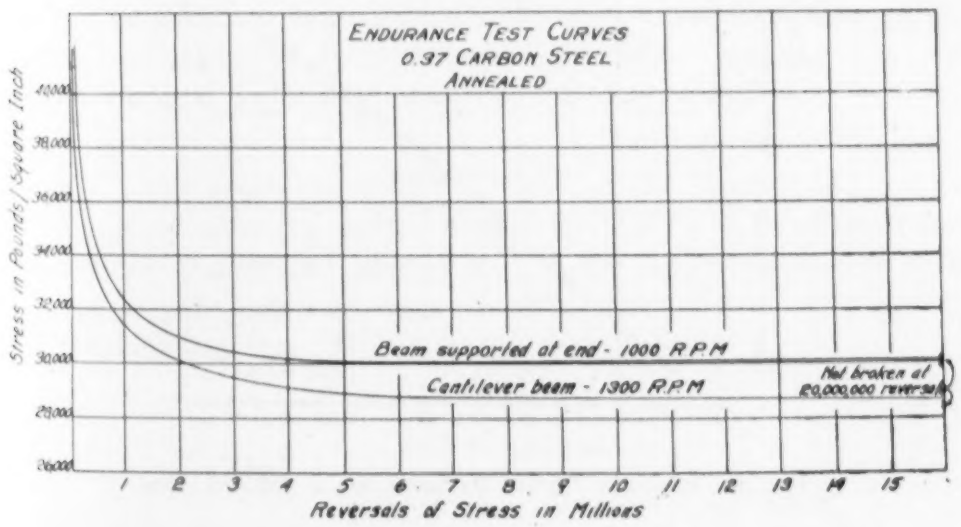

Fig. 9—Endurance Curve for a 0.37 Per Cent Carbon Steel, Annealed.

for a stress cycle of 20×10^6 the test piece must run continuously for at least twelve days. The repeated shock test can be used as

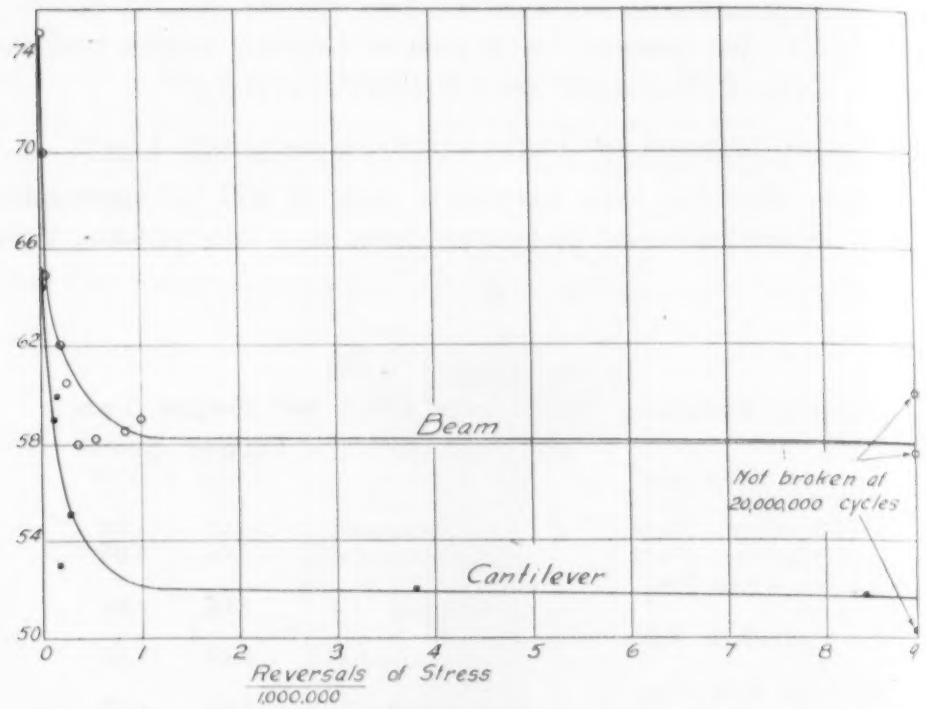

Fig. 10—Endurance Curve for a 0.37 Per Cent Carbon Steel, Heat Treated.

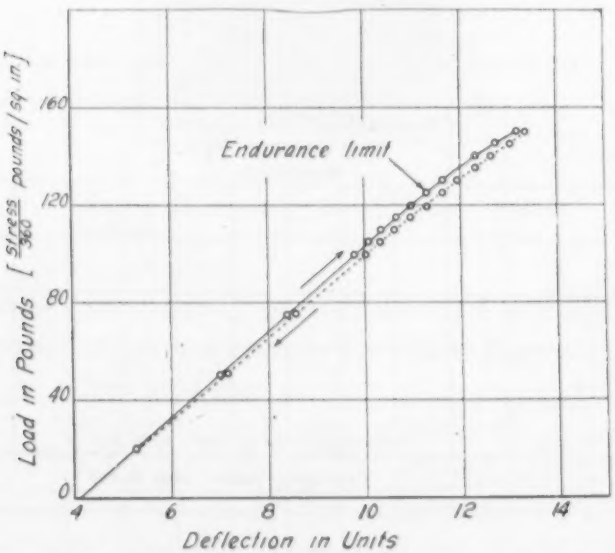

Fig. 11—Deflection Curve (Dynamic) for a 3½ Per Cent Nickel Steel.

a check on these long tests once the values from these long tests for one state of the material are at hand. There is, however, several short cuts to the determination of this endurance value.

One of these will be discussed, namely, the "deflection" method. In this test, one test alone is necessary although two are desirable and the endurance limit can be determined in thirty minutes. A mirror is fixed in the end of the rotating test piece and by a suitable arrangement of telescope and scale the values of deflection and corresponding load are obtained. From this data a curve is drawn having stress as ordinates and deflection as abscissae. The point at which stress ceases to be proportional to deflection is the endurance limit of the material. A curve of this nature for nickel steel is shown in Fig. 11. This method originally used at the National Physical Laboratory, England, gives very good results and the only limitation imposed on its use at this time by the writer, is that the endurance value so found must not exceed the elastic limit in tension.

From these remarks it will be appreciated that there is a relation between repeated shock and endurance tests. Since a series of repeated shock tests can be made in a few hours while the endurance tests take weeks, this relation will, when further worked out, tend to make dynamic testing possible commercially. Furthermore, by the development of such short methods as that of deflection, the time of determining endurance limits for steel under reversed stress will be further reduced. The only caution which the writer advances is that we should know these tools thoroughly before we begin to apply them. Otherwise, repeating the old adage, "a little knowledge may become dangerous."

Conclusion

In conclusion the writer wishes to emphasize the importance of dynamic testing and believes that in the future the use of such will be largely extended towards obtaining the best material for specific applications.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested to Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 96. Can the structure of a piece of steel be determined by the microscope applied to the fracture of a cross section, without polishing and etching the fracture, say of a stamping die 6 x 2 x 3½ inches, that has been hardened and broken in half, that is, are the different structural phenomena known as austenite, martensite, sorbite, ferrite, etc., so determinable?

QUESTION NO. 97. What degree of heat is required to change austenite to martensite, troosite, etc?

QUESTION NO. 98. What heat treatment will give a pure martensite structure throughout the hardened area of a piece of steel 6 x 2 x 3½ inches?

ANSWERS TO OLD QUESTIONS

QUESTION NO. 67. What is the reason for the fact that a piece of steel quenched in brine will be harder than the same piece of steel would be if quenched in water, providing that the quenching temperatures and quenching medium temperatures are the same in each case?

QUESTION NO. 69. Is sulphur up to 0.10 per cent detrimental to the quality and physical properties of an automotive steel.

QUESTION NO. 72. What elements are conducive to good electric butt-welding of steels?

QUESTION NO. 73. Does electric butt-welding destroy the physical properties developed in a steel which has been heat treated prior to the welding operation?

QUESTION NO. 74. Why shouldn't a bar of steel rolled from a locomotive axle be better than one rolled direct from the billet made from the original ingot?

QUESTION NO. 83. In annealing high-carbon tool steel in an open-fire furnace 6′ x 12′ is it likely that sulphur would be imparted to the steel by the use of producer gas made from coal unusually high in sulphur, say around 1.50 to 2.00 per cent?

QUESTION NO. 85. What is the best method of preventing carburization in holes, or in the bore of parts to be case hardened?

QUESTION NO. 92. What is meant by reduction of area in tensile testing of metals?

QUESTION NO. 93. What are the more common methods of quenching ordinary taps? Are they quenched all over and the shanks drawn, or are they quenched only on the threaded portions; or are both the threaded portions and the tangs quenched, leaving the center portion of the shank soft?

QUESTION NO. 94. What are the most salient causes of the explosive disruption of many hardened steel articles?

QUESTION NO. 95. What is meant by "self hardening" steels?

Reviews of Recent Patents

1,450,947. Forging Press. David R. Gill, Erie, Pa., assignor of one-half to Harold M. Sturgeon, Erie, Pa.

This invention relates to a forging press which comprises a plurality of forging dies each having forging surfaces encircling the axis of the pass, one end of said forging surface being out of the plane of the other end thereof and the radius thereof progressively decreasing from the entrance end of the exit and thereof, said dies being interjacent of each other and forming a conically shaped pass therethrough, and mechanism adapted to support said dies and rotate each die around an axis offset from the axis of the other die.

1,451,333. Art of Making Electrolytic Iron. Frederic A. Eustis, Milton, Carle R. Hayward, Quincy, and Henry M. Schleicher and Donald Belcher, Boston, Mass., assignors, by direct and mesne assignments, of one-half to said Eustis, and one-half to Charles Page Perin, New York City.

This refers to an art of making electrolytic iron which comprises reducing a ferric solution by means of an electric current to a ferrous state, and then transferring the ferrous solution to a separate electrolytic cell to which the ferric solution has no access and depositing iron from the ferrous solution by electrolysis in said separate cell.

1,452,232. Alloy. Carl J. Zaiser, Milwaukee, Wis., assignor to American Metal Products Company, Milwaukee, Wis., a corporation of Wisconsin.

This patent refers to an alloy consisting of the following ingredients in substantially the following proportions, namely: Iron—13 to 60 per cent; Copper—82 to 30 per cent; Aluminum—5 to 10 per cent.

1,452,480. Apparatus for Casting Metals. Nathaniel K. B. Patch, Buffalo, N. Y., assignor to Lumen Bearing Company, Buffalo, N. Y., a corporation of New York.

This invention relates to an apparatus for casting metals under the pressure of centrifugal force, comprising a rotatable head, and a molding flask mounted on said head to rotate therewith, said flask having a molding cavity in its upper portion and a comparatively deep well for molten metal in its lower portion communicating with said molding cavity.

News of the Chapters

BOSTON CHAPTER

The Boston chapter of the American Society for Steel Treating held a meeting on May 24 which was the last meeting of the year. The speaker for this evening was G. C. McCormick, assistant metallurgist, Crompton & Knowles Loom Works, Worcester, Mass., who chose for his subject "Use and Abuse of Pyrometers." Mr. McCormick pointed out the factors to be mindful of in every pyrometer installation and explained the principles of pyrometer operation. This paper was very well received and raised very active discussion, proving that there are many essential features of pyrometer equipment that the general steel treater does not know about.

Following the presentation of this paper a banquet was held, a photograph of which is given on the next page. The election of officers for the ensuing year took place at this meeting which resulted in the following being elected: Chairman, H. E. Handy; vice chairman, V. I. Homerberg; secretary-treasurer, G. E. Davis. The retiring chairman and secretary with the new officers will comprise the executive committee and it is felt that with a new start the chapter may be brought to the front.

The Boston chapter of the American Society for Steel Treating held a special meeting of the executive committee on September 7. At this meeting the following committees were elected: Membership committee, L. H. Wetherell, chairman; D. A. Black, E. A. Meade, C. L. Stott, H. B. Parker, Fred Lovejoy, K. A. Juthe and H. W. Foster, members; Life-Saving committee, R. E. Belknap, chairman and J. L. Faden and T. L. Kirkpatrick, members; Reception committee, W. W. Cummings, chairman and I. H. Cowdrey and L. Zurback, members; Finance committee, A. N. Everett,

Boston Chapter Banquet at City Club, Boston, May 24, 1923

chairman and L. J. Heath, member; Research committee, L. D. Hawkridge, chairman; C. E. Karle, F. H. Kingdon, F. C. Langenberg, I. H. Cowdrey and J. A. Erickson, members; and Meetings committee, W. E. Latham, chairman and G. P. Beck and S. W. Parker, members. The duty of the respective committees is as follows: Membership committee, to endeavor to increase membership of the chapter; Life-Saving committee, to co-operate with Membership committee to retain members who have been dropped for dues and for various other reasons; Reception committee, to see that all members are made acquainted with each other and given the proper welcome; and the Finance committee, to take care of the finances of the chapter and to audit the treasurer's books.

CHICAGO CHAPTER

The Chicago chapter of the American Society for Steel Treating have recently announced that there will be evening classes in heat treating, metallurgy and metallography given by Lewis institute, who are co-operating with the Chicago chapter.

The school year is divided into two semesters beginning on October 8, 1923 and February 11, 1924, respectively. The class work is under the supervision of William H. Potter, a member of the executive committee of the chapter, and consists in the working out of various practical and theoretical problems from a heat treating and engineering standpoint. The work is of interest and value to heat treaters, draftsmen, engineers, etc. The classes meet twice a week and discuss their problems in the classroom with the aid of lectures and stereopiticon slides. They also have access to a metallurgical laboratory and forge shop.

The heat treating class meets from 6:30 to 9:30 p. m. using as a textbook "Steel and Its Heat Treatment" by D. K. Bullens. The first quarter of each semester is spent in the forge shop, making a study of the various types of equipment. The remainder of the time is equally divided between work in the forge shop and lectures in the classroom.

The metallurgical class meets from 6:30 to 8:15 p. m.

using "The Metallurgy of Iron and Steel" by Bradley Stoughton as a textbook. The work of this class consists of a series of lectures on the art of steel making, physical tests, etc.

The class in metallography meets from 6:30 to 9:30 p. m. having as their textbook "The Metallography of Iron and Steel" by Albert Sauveur. This work consists of the selection, preparation and photography of specimens taken from ferrous and nonferrous metals as well as the interpretation of micro-photographs and specification writing.

DETROIT CHAPTER

The Detroit chapter of the American Society for Steel Treating held its first meeting of the fall season on September 17 in the General Motors building at 8:00 p. m. The speaker of the evening was J. W. Alden, United Alloy Steel Corporation, Canton, Ohio, who chose for his subject "Melting and Calculating of a Heat of Alloy Steel and also Various Types of Ingots and Brick Tops." Mr. Alden gave a very capable presentation bringing out many interesting and instructive points.

The meeting was preceded by dinner at 6:30 p. m.

INDIANAPOLIS CHAPTER

The Indianapolis chapter of the American Society for Steel Treating held its first meeting of the fall season at the Hoosier Athletic club on September 10, 1923. Dinner was served at 6:30 p. m. after which a short business session was held.

The program for the entire year was outlined at this meeting. It was planned to conduct a course on automotive construction to be in session every other month, and in this way it is hoped to stimulate interest in round table discussion.

The speaker for this meeting was Earl Smith, metallurgist, Central Steel Company, who gave a very interesting

talk on "Steels in Automotive Construction." This presentation was followed by lively discussion. Lantern slides were also shown explaining operations in the steel mill.

MILWAUKEE CHAPTER

The Milwaukee chapter of the American Society for Steel Treating held a meeting on Tuesday, September 25 at 8:00 p. m. in Hotel Blatz. The paper of the evening entitled "Industrial Electric Heating" was presented by H. E. Scarbrough, industrial heating engineer, General Electric Company, Chicago. Having had extensive experience in this subject, Mr. Scarbrough presented his paper in a very capable manner, outlining briefly the existing applications of electric heating, including low and high-temperature production.

Preceding the meeting, dinner was served at 6:30 p. m.

NORTH WEST CHAPTER

The North West chapter of the American Society for Steel Treating held its first meeting of the fall season on Tuesday evening, September 25 at 7:45. The paper of the evening was presented by Norman Conn, metallurgist, Minneapolis Steel & Machinery Company, who chose for his subject, "Hardening Small Tools and Dies." Mr. Conn, having had an extensive practical experience in this subject covered the general practice of hardening small tools and dies and exhibited a number of failures, explaining their causes. Lively discussion followed the presentation of the paper which was very interesting and instructive.

PITTSBURGH CHAPTER

The Pittsburgh chapter of the American Society for Steel Treating held its first meeting of the fall season on September 4, 1923, at 8 p. m. in the Blue Room of the William Penn hotel. The paper of the evening, entitled "An Illustrated Explanation of Some of the Metallurgical Terms Relating to

the Microstructure of Steel," was presented by N. B. Hoffman, chief chemist and metallurgist, Colonial Steel Company. This paper was illustrated by lantern slides. This meeting was well attended and an enjoyable time was spent by all. Dinner was served in the Engineers Society rooms at 6:30.

The Pittsburgh chapter held its October meeting on the second of the month in the Crystal Parlor, William Penn hotel. The speaker of the evening was J. E. Burns Jr., district sales manager, E. F. Houghton & Company, Indianapolis, who chose for his subject "Quenching Media." Mr. Burns, who is an authority on this subject, gave a very capable presentation and much discussion was brought forth. Dinner was served preceding the meeting at 6:30 in the Engineers Society rooms.

SOUTH BEND CHAPTER

The South Bend chapter of the American Society for Steel Treating held its first meeting of the 1923-24 season on Wednesday, September 26, at 7:45 p. m. in the South Bend Y. M. C. A. The program for the evening consisted of a paper presented by Professor Knowles B. Smith, professor of mining and metallurgy, Notre Dame University, Notre Dame, Indiana, entitled, "The Occurrence and Mining of Iron Ore." Lively discussion followed the presentation of this interesting subject.

TRI CITY CHAPTER

The Tri City chapter of the American Society for Steel Treating held a meeting on September 20 at 8:00 p. m. in the Davenport Chamber of Commerce. The program of the evening consisted of two papers being presented, one by C. B. Rose, manager, Moline Plow Company, tractor plant, Rock Island, Ill., on the subject of "Value of Heat Treating to the Industries" and "Drop Forging" by R. Henry, superintendent of forge work, also of the Moline Plow Company. Both of these subjects being of keen interest, lively and instructive discussion was brought forth.

OBITUARY

Major Robert S. Oberly, office of the chief of ordnance of the War Department, died at Walter Reed hospital, Washington, D. C., on September 4, 1923.

Major Oberly was born in Easton, Pa., September 22, 1885. He was educated in the schools of Easton and was graduated from Cornell university in 1908 with a degree in mechanical engineering. He entered the army in December, 1911, as a second lieutenant of coast artillery. He was made first lieutenant of ordnance in June, 1914, and captain in September, 1916. In January 1918, he was made major of ordnance in the national army and lieutenant-colonel, September, 1918. Major Oberly had served at Fort Monroe, Sandy Hook, Manila, Aberdeen Proving Grounds and in Washington. He was in charge of the arsenal order section in the War Department. Major Oberly has been a member of the Washington chapter of the American Society for Steel Treating since January of this year.

ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member, and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

NEW MEMBERS

BARR, WALTER D. (M-9), 2920 Smallman Street, Pittsburgh.
BROST, FRED G. (M-8), 55 Court Street, Lancaster, N. Y.
CASTNER, WILLIS H. (M-9), Bethlehem Steel Co., Reading, Pa.
CHENEY, ARTHUR M. (M-7), 40 Grove Street, Bristol, Conn.
CLAUSEN, H. (M-5), Haregrade, Copenhagen, Denmark.
FLORENCE PIPE FOUNDRY & MACHINE CO. (S-9), Florence, N. J.
FOSTER, JAMES L. JR. (M-9), Warren Tool & Forge Co., Warren, Ohio.
GLADDEN, JOHN E. (M-9), 553 Celeron Street, Pittsburgh.
HOLDER, PERCY E. (M-9), 2164 N. Pennsylvania Street, Indianapolis, Ind.
JOHNSON, GEORGE WARREN (M-9), 731 Orchard Avenue, Avalon, Pa.
KESSELL, ROY (M-8), Lancaster Machine & Knife Works, Lancaster, N. Y.
MARR, WILLARD P. (M-7), 613 N. Colony Street, Meriden Conn.
REYNOLDS, E. M. (M-9), R. F. D. No. 2 Monaca, Pa.
SMITH CORPORATION, A. O. (S-8), P. O. Box 284, Milwaukee, Wis.
STEPHENSON, A. W. (A-9), 6728 N. Sydenham Street, Philadelphia.
TAYLOR, W. DUNCAN (M-9), 2920 Smallman Street, Pittsburgh.
VAN LYEN, HAROLD N. (A-9), 7946 East Lafayette Avenue, Detroit.
WALTON, E. THOMAS (M-9), P. O. Box 671, Midland, Pa.
WOODS, THOMAS J. (M-8), 735 Ellicott Street, Buffalo, N. Y.

CHANGES OF ADDRESS

ALLA, E. S. from 135330 Thomson Avenue, Highland Park, Michigan to 1919 Fourth Avenue, Bay City, Michigan.

BACON, WM. from Reed-Prentice Company, Worcester, Mass., to N. Oxford, Mass.

BENSON, SIMON from Miehle Printing Press & Manufacturing Co., Chicago, to Vincennes University, Vincennes, Indiana.

BONNING, F. W. from 288 Broadway, Malden, Mass., to 52 Rowe Street, Melrose, Mass.

BRUNN, FRANK from Hoover Steel Ball Co., to Hoover Steel Co., Ann Arbor, Mich.

CAUGHEY, E. G. from Ohio Road, Sewickley, Pa., to 729 North Third Street, Steubenville, Ohio

CONNELL, W. L. from 2932 First Avenue, to 4532 Minnehaha Avenue, Minneapolis, Minn.

FREDERICK, JOHN B. from Barber Colman Co., to National Lock Co., Rockford, Ill.

GEPHART, H. O. from 61 Whalley Avenue, New Haven, Conn., to Western Tool & Manufacturing Co., Springfield, Ohio.

GREGG, JAMES L. from Box 90, Rolla Mo., to 1306 West Fifth Avenue, Gary, Ind.

GRILL, C. H. from 5479 Harper Avenue, Chicago, to 2085 50th Street, Philadelphia.

JOHNSON, G. D. from 523 Hight Street, Easton, Pa. to 632½ Penna Avenue, Elmira, N. Y.

KENNEDY, N. W. from 5013 Smedley Street to 2031 E. Dauphen St., Philadelphia.

LAURY, W. H. from 256 E. Goepp Street, Bethlehem, Pa., to 224 S. Guadalupe Avenue, Redondo Beach, Cal.

LUEBKE, OTTO from 924 Pennoyer Street, Grand Haven, Mich., to 1254 Vine St., Beloit, Wis.

MARSHALL, L. K. from 391 Flower City Park, to 158 McKinley St., Rochester, N. Y.

PATRICK, W. from 26th & Western Ave. to Blue Island & Western Ave, Chicago.

ROBINSON, J. E. from 1421 Cedar Street, Milwaukee to J. I. Case Threshing Machine Co.,Racine, Wis.

ROOT H. H. from 126 Lathrop St., Beverly, Mass to 184 Moody St., Waltham, Mass.

SMITH, R. P. from Burroughs Adding Machine Co., Detroit to 17 Kamberton Drive, Pleasant Ridge, Detroit.

STUMP, F. A. from 210 Smith Ave., to 722 Shepard St., Lansing, Mich.

WEISE, ALERED M. from 19 Wall Street to Marlin Fire Arms Corp., New Haven, Conn.

WHITNEY, L. L. from 1002 Hyslop Place to American Steel Foundries, Hammond, Ind.

WOOD, HAROLD F. from 6745 Ridgeland Ave. to 11039 South Irving St., Chicago.

MAIL RETURNED

SCHMITT FRANK, International Manufacturing Company, Detroit.

STONE, HARRY, Automotive Products Corporation, Hazelton, Pa.